FLEXIBLE PIPE RESPONSE TO INCREASING OVERBURDEN STRESS

By

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To my parents, for their invaluable support has allowed me to achieve all of my goals

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
FDOT	Florida Department of Transportation
FEA	Finite Element Analysis
HDPE	High Density Polyethylene
PSI	Pounds per Square Inch
PVC	Polyvinyl Chloride

Abstract of Thesis Presented to the Graduate School
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FLEXIBLE PIPE RESPONSE TO INCREASING OVERBURDEN STRESS

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Inspection of flexible pipe installation occurs when three feet of soil is placed to make sure the pipe is less than five percent deflected. This research aims to define how much more deflection occurs after additional overburden stress is applied. With this the Florida Department of Transportation (FDOT) will be able to identify pipes that are within allowable deflections at time of inspection but may exceed maximum deformations after they are finished being buried.

The pipes that were targeted in this project were 36 inch High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC) and steel. They were tested using the Soil Box at the University of Florida. The ten feet wide, 20 feet long, and eight feet tall chamber allows simulated depths of up to 40 feet. Portholes in the side of the box allow deflection readings to be taken as the load is applied.

As expected the steel being the most rigid deflected the least amount. The PVC showed even more movement. The most backfill sensitive pipe, HDPE, had greater deformations than all the pipes and when subjected to a trench box installation was the maximum.

Overall, the results obtained during this research have proven to show a good trend towards flexible pipe characteristics. This project will continue on to test 24 inch HDPE and steel pipes. Pending these results and comparisons with finite element analysis (FEA) modeling conclusions can be made to better aid the FDOT in on site flexible pipe inspection.

CHAPTER 1
BACKGROUND

Purpose

The purpose of this project is to assist the Florida Department of Transportation in further defining pipe inspection standards. When a flexible pipe is installed into the ground it is first inspected by the FDOT to make sure the deflection of that pipe is no greater than five percent of the diameter. If there is more deflection then the section has to be taken out and a new one installed.

This initial inspection occurs in the beginning of the installation process when the pipe is accessible by the FDOT. After passing it could be buried even deeper. This project aims to help with identifying pipes that may be within the five percent tolerance range at time of assessment but after the full overburden has been placed has surpassed this range. This is being done with the use of the Soil Box at the University of Florida.

Soil Box

The Soil Box, shown in Figure 1-1, is 10 feet wide, 20 feet in length and eight feet high. The scale of this box allows tests to be done on full scale pipes. The box is reinforced with steel I-beams to allow the pressure from the large loads of simulated overburden stress to keep the walls from deforming.

The reinforcement of the box allows forces to be applied that stimulate overburden stresses equivalent to 40 feet of burial. With the ability to look through portholes during testing deflections can be measured. As the simulated overburden is applied deflection readings are taken. This allows the movement of the pipe to be compared with how

deep it is buried. The development of the design of this test chamber was based on tests that were done in the past in a laboratory setting (Brachman et al. 2000).

Previous Tests

Previously there were two tests performed in the Soil Box. One test was on two 36 inch diameter HDPE pipes. The next test was a calibration test to get a better idea of how the pressure applied by the loading mechanism related to a simulated overburden stress on the pipe. This report is a continuation of the previous research which goes on to compare different flexible pipes along with different installation techniques.

Figure 1-1. The Soil Box at the University of Florida Coastal Engineering Laboratory. Photo credit: Z. Faraone.

CHAPTER 2
POLYVINYL CHLORIDE (PVC) PIPE TEST WITHOUT TRENCH BOX

Pipe Preparation

The first step in preparing for a full scale test is to prepare the pipes for installation into the Soil Box. The pipes being tested were 36 inch diameter F949 Polyvinyl Chloride. They were first cut down to just under 10 feet in length in order to fit in the box.

Next, the corrugation was shaved off both ends in order to allow the flexible membrane sealing system to fit on them properly when placed into the box. This is shown in Figure 2-1. The membrane will allow them to move freely in the box without allowing soil come out of the portholes. Without this system it would be impossible to monitor the deflection while keeping all of the soil in the box and allowing the pipe to deflect and move freely.

The pipes were then pre-deflected four percent or 1.44 inches. The first attempt was to use the same method as used for the HDPE pipes. Deflecting them consisted of using three turnbuckles placed inside the pipe. These turnbuckles were then twisted outward into steel channels that ran along the length of the pipe. Once a four percent deflection was achieved this process was concluded.

This method did not work because the stiffness of the PVC pipes was too great for the turnbuckles being used. A failure of one can be seen in Figure 2-2. This problem was fixed by fabricating stronger ones at the Coastal Engineering Laboratory. They were successful and both pipes were deflected 1.44 inches. The pre-deflecting is done to further simulate field conditions on site and during installation. The pipes were now ready to be installed into the Soil Box.

Soil Box Preparation

The first step in preparing the Soil Box for the test was to remove the North and South porthole covers. They were removed with a custom made extractor/positioning device. The covers are heavy and awkwardly placed on the box making it difficult to be removed by hand. This device made this process a lot quicker and easier. It can be seen in Figure 2-3. Removing them allow the pipes to be monitored during testing.

After the porthole covers were removed the first layer of Visqueen was put into the box. It was placed so that it did not interfere with the French drain on the South end of the box. The first layer installation is shown in Figure 2-4. The next step was then to install the steel rings that go around the portholes inside the box that connect the flexible membrane sealing system to the pipes. The installed rings can be seen in Figure 2-5. A layer of silicone grease was then sprayed on the first layer of Visqueen and then the second layer of it was placed over the other. These two layers with grease in between are installed to help reduce friction along the side walls. This way the majority of the load will be transferred into the soil and not the walls. The final product of this process can be seen in Figure 2-6.

A 12 inch layer of soil was then placed into the Soil Box. This was achieved by using a front end loader to dump soil onto the box floor. The soil was the then shoveled around and evened out. Then it was compacted with a vibratory plate compactor. Figures 2-7, 2-8, and 2-9 show this layer before, during, and after compaction. The first layer is compacted to simulate the exposed surface a pipe would be placed on during field installation.

Nuclear density tests were done to make sure the first layer of soil was evenly compacted all around. The equipment used to obtain densities can be seen in

Figure 2-10. Earth pressure cells were then placed in locations below the locations of the pipes. Figure 2-11 shows one of the cells used. The locations of these instruments can be seen in Figure 2-12.

The Soil Box was now ready for the installation of the two PVC pipes. They were picked up with a fork lift and driven to the North side of the box as shown in Figure 2-13. They were then rolled into place. The flexible membrane sealing system was then installed on the East and West sides of each pipe. Before and after pictures of this installation can be seen in Figure 2-14.

The flexible membrane sealing system consists of a rubber sheet that is wrapped around the end of the pipe and the steel ring on the box wall. The rubber is then held in place with two metal hose clamps. One hose clamp goes around the pipe end and another goes around the steel ring. Now the pipe is ready for soil to be placed around it. Figure 2-15 shows them installed.

The North end of the box was then bolted onto the box. This is achieved by hoisting the end up with the lift truck and pinning it against the box while numerous nuts and bolts and placed. This process is shown in Figure 2-16. The North end was then sealed to make sure no water leaked out. The two layers of Visqueen were installed in the same fashion as the rest of the box was and the remaining soil for the first 12 inch layer was put into place.

Filling of the box continued with 18 inch lifts. Placing the soil in the box was done by using a lift truck to hoist a bucket of soil into the box. Figure 2-17 shows the use of the lift truck for filling. The soil was then emptied into the box and distributed around with shovels. This process was repeated until the 18 inch lift height was achieved. Lifts

of soil are added until the appropriate height is reached. Nuclear density tests were done at each lift. The soil was not compacted with a compactor to simulate poor installation techniques. Figures 2-18, 2-19, and 2-20 show the locations of these tests.

Throughout the filling of the Soil Box earth pressure cells were strategically placed to obtain the most data. Figures 2-21, 2-22, 2-23, 2-24, and 2-25 show the placement of these cells. These locations are almost the same as the locations of the cells during the HDPE test with the addition of an array of cells at a level eight inches above the pipes. The installation is shown in Figure 2-26. The cells at this level were used to control the pressure in the lift bags in order to get a uniform pressure at this level.

Once the soil reached the appropriate height that allowed just enough room for the loading mechanism the saturation process began. Watering the soil aims to simulate the fluctuating high ground water tables in Florida. The soil was saturated by using a lawn sprinkler to make sure the entire surface area of the top of the soil was reached as shown in Figure 2-27. The sprinkler was left running over night for approximately 18 hours until puddles formed on the top of the soil signaling that the soil had been fully saturated. This is the same process that was used to saturate the soil for the HDPE test to provide uniform testing parameters.

After reaching the desired level of saturation the loading mechanism could be installed. This mechanism consists of 10, three-quarter inch thick steel plates which lie on the surface of the soil. On top of the plates lie lift bags which apply the force to the plates to simulate increasing overburden depths. The plates are placed on the soil by hoisting them over the box with a fork lift. After the calibration test it was decided that additional small lift bags would be added to each of the small plates as shown in

Figure 2-28. These additional lift bags allow for increased simulated overburden depths as well as a more uniform distribution of pressure throughout the box.

The small lift bags are rotated slightly off center of the small plates because of the pick points on the plates being in the way. With the additional fittings to allow an additional bag on each plate it made it so the bags needed to be rotated slightly in order to fit on the plate. This rotation however doesn't affect the loading mechanism because the full footprint is still on the plate. Finally, the lift bags are then connected to the air source and checked to make sure that all the fittings are working by applying 10 PSI of air pressure which can be seen in Figure 2-29.

The final step in preparing the Soil Box for testing was to install the three top sections. This was done by hoisting each section onto the box with the lift truck and then bolting it down to the rest of the box. Figure 2-30 shows this process. Each end section is bolted down then the middle section is bolted down last to keep the walls of the box from bowing out after the middle steel bar is removed. This can be seen in Figure 2-31. The Soil Box was now ready for testing.

Testing

The load was applied in 10 PSI increments to the large lift bags until movement was seen by the pipe deflection monitoring system. After that the load was applied in five PSI increments. The load was held for one hour and then deflection readings were taken. For one-third and two-thirds of the total increments the load was held and deflection readings were taken at one hour, four hours, and eight hours. During the final load increment deflection readings were taken at one hour, four hours, eight hours, and 24 hours after the load was applied. The monitoring was done at these time increments

to show how the pipes were deflecting over time. Table 2-1 shows the loading increments, deflection readings timing and simulated overburden.

During this process the pressure was being increased in the large lift bags by five PSI and then the pressure in the small lift bags was being adjusted in order to get an even distribution of pressure throughout the pressure cells located eight inches above the pipes.

After the final load was reached and the deflection readings were taken the load was then reduced in five PSI increments. After the load was reduced deflection readings were taken an hour later and this continued until there was no air pressure being supplied to the lift bags. At this point the test was finished and the data were ready to be analyzed.

Pressure data were taken throughout the whole loading and unloading sequence. After the data were acquired it was put into a Microsoft Excel® format for further analysis. The data were then sent to Mr. Bryan P. Strohman of Simpson Gumpertz & Heger. This data will be used for the FEA modeling of the Soil Box.

The pipe deflection data were gathered using a displacement laser. This laser was mounted on a trolley which is sent through the pipe multiple times to read the profile of the pipe in the four quadrants. The laser mounting system is shown in Figure 2-32 with the laser at the far end of the pipe.

The data were then analyzed using Microsoft Excel®. Different plots were made to show the percent deflection of the pipe versus time, length of the pipe, and simulated overburden.

Soil Box Disassembly

With the conclusion of the PVC pipe test the Soil Box was ready to be disassembled and emptied. This process starts with the removal of the box lids which requires removing multiple nuts and bolts. The middle section is first removed. A steel bar is then placed along the middle of the box to keep the walls of the box from bowing out from the force of the soil after the lids are removed. Once the steel bar is installed the two end top sections are removed.

The removal of the three sections of the box top is followed by the removal of the 14 lift bags and the 10 steel plates the lift bags sit on. These plates are removed by attaching a steel chain to each corner and then hoisting them out of the top of the box with an extension on the fork lift. Steel plate removal is shown in Figure 2-33.

The North side of the box was then removed to make it easier to remove the soil, which can be seen in Figure 2-34. Removing this side allows a front end loader to enter the box via a ramp and remove large quantities of soil. This process is shown in Figure 2-35. The soil was carefully removed with shovels around the locations of the earth pressure cells to make sure none were damaged by the front end loader. When the pipes were uncovered they were removed with the forklift. Figure 2-36 and Figure 2-37 shows the North and South pipes being uncovered.

Once all of the soil was removed the first layer of Visqueen was cleaned of all soil and the box was cleaned out as best as possible. The Soil Box was now ready to be prepared for the next test as shown in Figure 2-38.

Results

Following the PVC pipe test data reduction and analysis took place to see how much the pipes deflected and under what overburden this occurred. The analysis is

broken up into two parts. The pressure analysis which calculates how much overburden was applied and the deflection analysis which calculates how much each pipe deflected at each pressure increment during the test.

An example of one plot from the pressure analysis can be seen in Figure 2-39. This particular plot shows the stress output from the cells located eight inches above the pipes running along the center line of the box. Since these outputs are not all exactly the same the loading mechanism will be refined to fix this problem.

With each series of tests the loading mechanism has been modified in order to provide a more uniform distribution of pressure throughout the Soil Box. With an array of pressure cells located eight inches above the pipes during the PVC test the lift bags were controlled to make these pressure cells receive the most equivalent amount of pressure as possible with two pressure regulators. This process allowed the pressure to be more evenly distributed but still had some room for improvement.

When filling the box it is difficult to get the soil to be exactly level at all points. This means that the soil level can be higher in some places and lower in others. When a pressure is applied to all of the lift bags the footprint for each bag may be different depending on the height of the soil under it. This difference in the size of the footprint will consequently apply a different load to the soil at each these locations. This makes it difficult to apply a uniform pressure throughout the box.

The idea to add a pressure regulator to each lift bag would allow the pressure at each bag to be adjusted according the pressure being shown in the pressure cells at the level eight inches above the pipes. This means each bag could have its pressure adjusted until the pressure was uniform throughout the whole box. This would eliminate

the need to perfectly level the top of the soil. These pressure regulators were added for the test on the steel pipes.

During the loading sequence the South pipe incurred a longitudinal crack along the invert of the pipe. This crack extended the whole length of the pipe which can be seen in Figure 2-40. The pipe at this time was subjected to approximately 14 feet of simulated overburden. The pipe had deflected a total of 5.1% at the time of the failure. After the failure the deflection was 5.5%. A drawing of the crack can be seen in Figure 2-41.

After the failure the test continued to see if the North pipe would fail. This would not be the case after reaching nearly 40 feet of simulated overburden at the end of the test.

Once the test had finished and the pipes were removed it was possible to further investigate the failure with the pipe outside of the Soil Box. Mr. Rod Powers of ConTech visited the Coastal Engineering Laboratory to take pictures and notes on the crack. Also, Dr. Jack J. Mecholsky Jr., a professor in the Materials Science & Engineering Department at the University of Florida, came by to examine the pipe and take pictures. Both Mr. Powers and Dr. Mecholsky received sections of the failed pipe to take back to their labs for further investigation into the pipes failure.

With the failure of the South pipe, the North pipe's deflection was used to evaluate PVC's performance. The two plots shown in Figures 2-42 and 2-43 are from the deflection data gathered of the North pipe's vertical diameter. The first plot shows the percent deflection of three points in the pipe as the increasing simulated overburden was applied. It ended up deflecting a total of 12.4% of its original diameter at a simulated depth of 38.5 feet.

The second plot shows the percent deflection of three points in the pipe over a 24 hour time period at one simulated overburden depth. Over this time period the plot shows that the pipe had not stopped deflecting. With more time it would eventually stop deflecting.

Finally, Figure 2-44 shows the PVC pipe's performance and the HDPE pipe's performance on the same plot. Here we see that during the HDPE pipe test the same overburden depths were not reached but it deflected at a faster rate than the PVC pipe. At the end of the test the HDPE pipe deflected around 0.5% more than the PVC pipe deflected.

Table 2-1. Loading sequence and deflection readings for PVC pipe test.

Pressure Applied to Large Lift Bags (PSI)	Deflection Readings taken x hours after pressure was applied	Simulated Overburden on North Pipe (feet)
0	1	5.16
10	1	7.68
15	1	8.85
20	1	10.90
25	1	12.04
30	1	13.22
35	1	14.64
40	1	17.12
45	1, 4, 8	18.39
50	1	19.30
55	1	20.41
60	1	21.67
65	1	23.33
70	1	24.43
75	1	25.56
80	1	26.75
85	1, 4, 8	27.96
90	1	28.83
95	1	30.53
100	1	31.77
105	1	32.97
110	1	34.32
115	1	35.05
120	1	36.22
125	1	36.97
130	1, 4, 8, 24	38.50

Figure 2-1. Corrugation shaved off of PVC pipe. Photo credit: Z. Faraone.

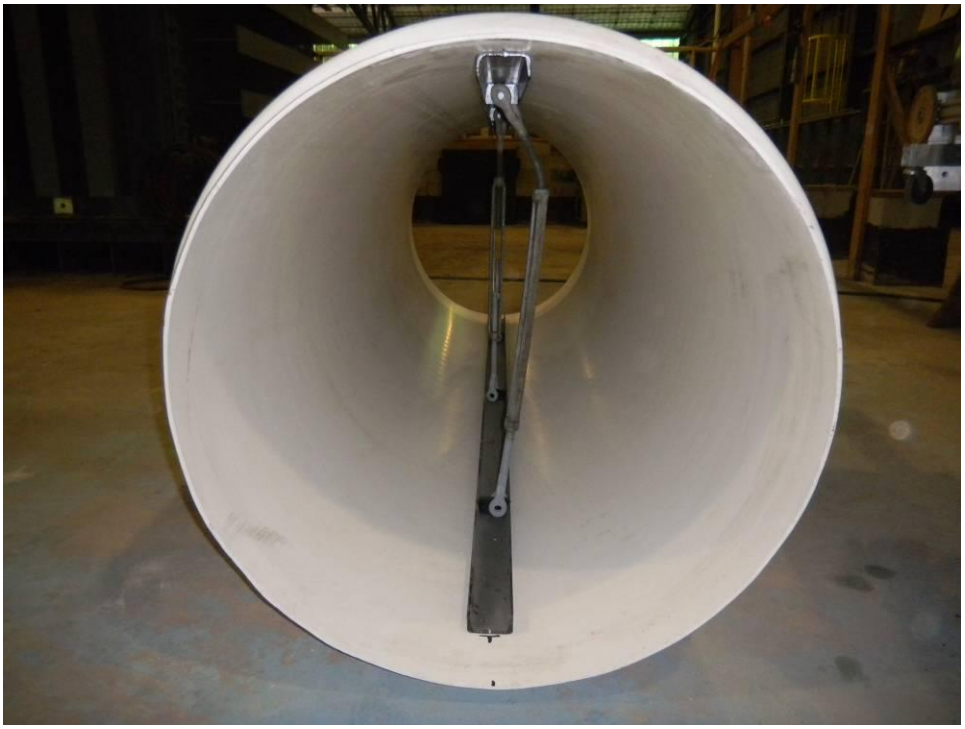

Figure 2-2. Turnbuckle failure during PVC pipe pre-deflection. Photo credit: Z. Faraone.

Figure 2-3. Porthole extractor/positioning device shown with uncovered porthole in background. Photo credit: Z. Faraone.

Figure 2-4. First layer of Visqueen installed while avoiding French drain. Photo credit: Z. Faraone.

Figure 2-5. Steel rings installed over first layer of Visqueen. Photo credit: Z. Faraone.

Figure 2-6. Two layers of Visqueen and steel rings installed into Soil Box. Photo credit: Z. Faraone.

Figure 2-7. First layer of soil placed. Photo credit: Z. Faraone.

Figure 2-8. First layer being compacted with vibratory plate compactor. Photo credit: Z. Faraone.

Figure 2-9. First layer of compacted soil. Photo credit: Z. Faraone.

Figure 2-10. Nuclear density testing device. Photo credit: Z. Faraone.

Figure 2-11. Earth pressure cell. Photo credit: Z. Faraone.

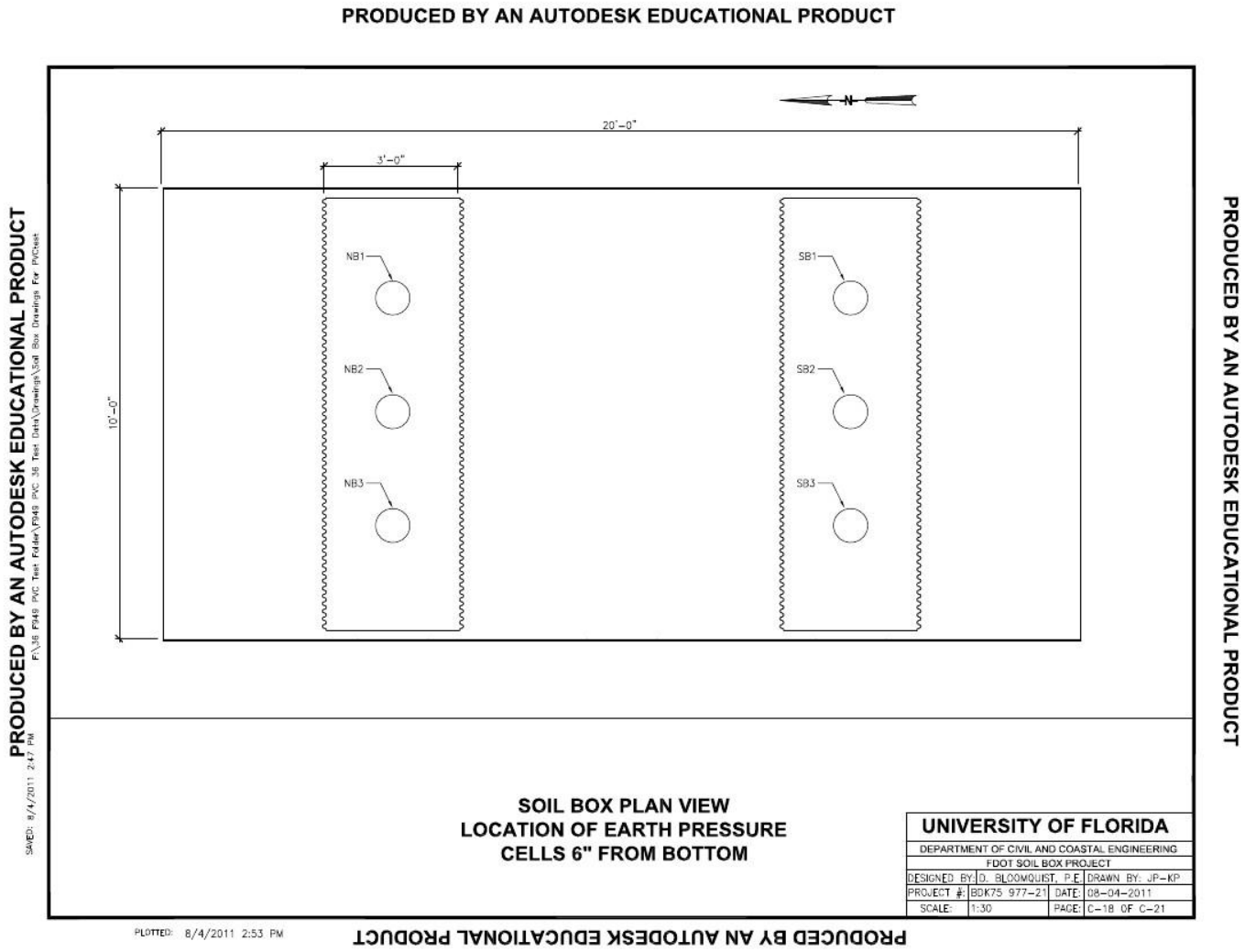

Figure 2-12. Plan view schematic of location of earth pressure cells below pipes. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 36). University of Florida, Gainesville, Florida.]

Figure 2-13. PVC pipe being placed into Soil Box with fork lift. Photo credit: Z. Faraone.

A B

Figure 2-14. Pipe installation. A) Before flexible membrane installation. B) After flexible membrane installation. Photo credit: Z. Faraone.

Figure 2-15. Both PVC pipes installed into the Soil Box. Photo credit: Z. Faraone.

Figure 2-16. Lift truck pinning North end against the Soil Box for installation. Photo credit: Z. Faraone.

Figure 2-17. Lift truck hoisting bucket of soil to be dumped into the Soil Box. Photo credit: Z. Faraone.

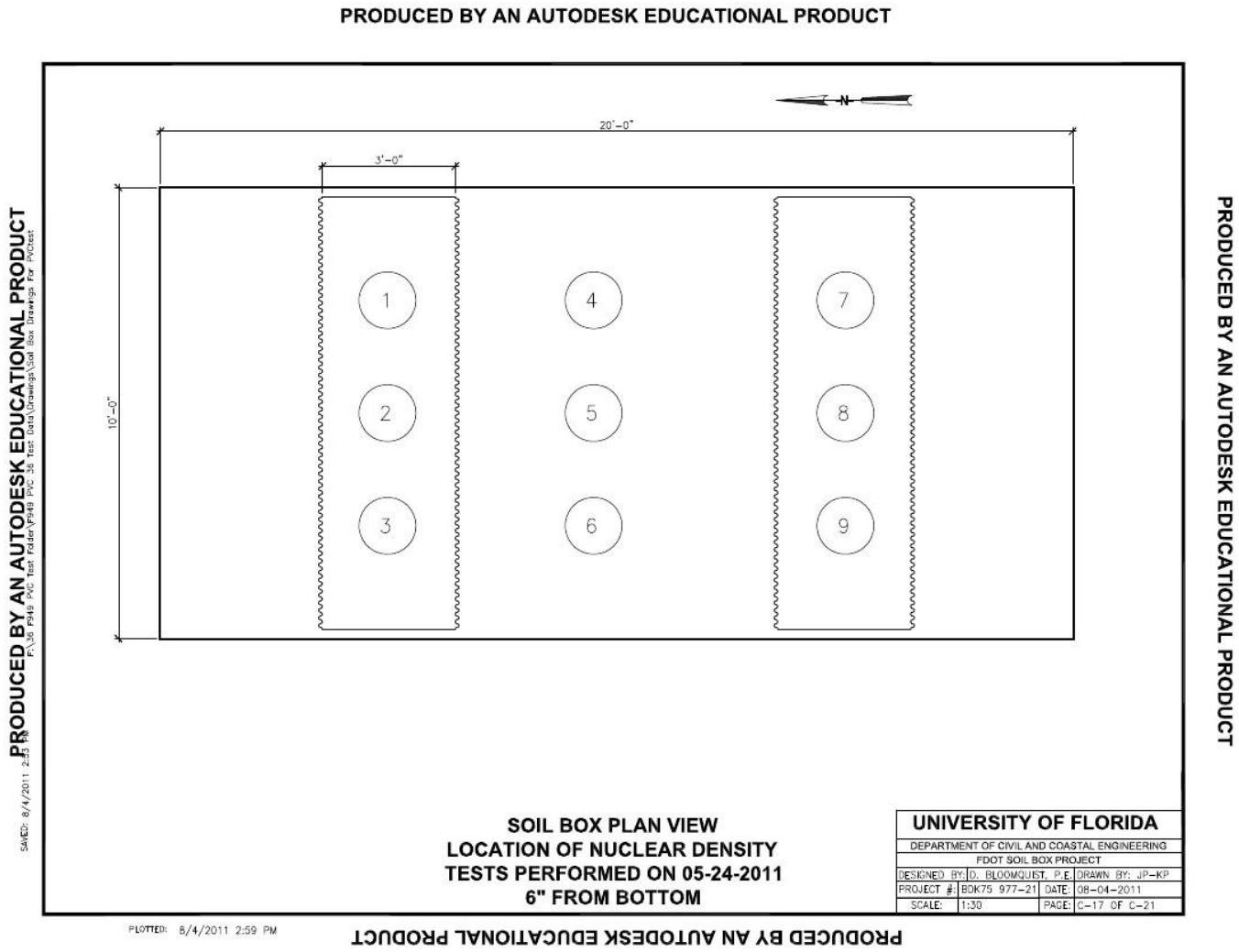

Figure 2-18. Plan view schematic showing the locations of nuclear density tests performed six inches from the bottom of the Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 29). University of Florida, Gainesville, Florida.]

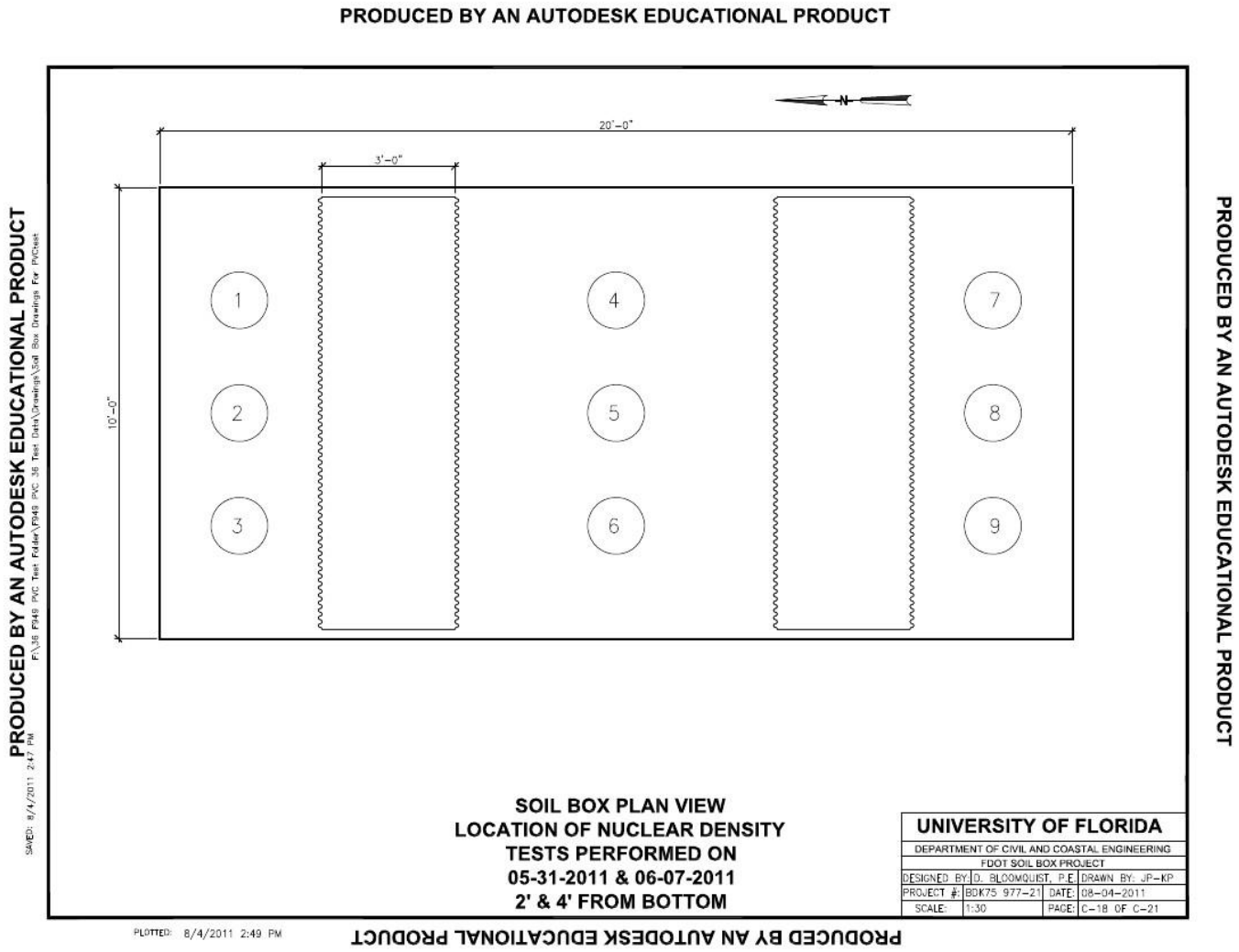

Figure 2-19. Plan view schematic showing the locations of nuclear density tests performed two feet and four feet from the bottom of the Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 30). University of Florida, Gainesville, Florida.]

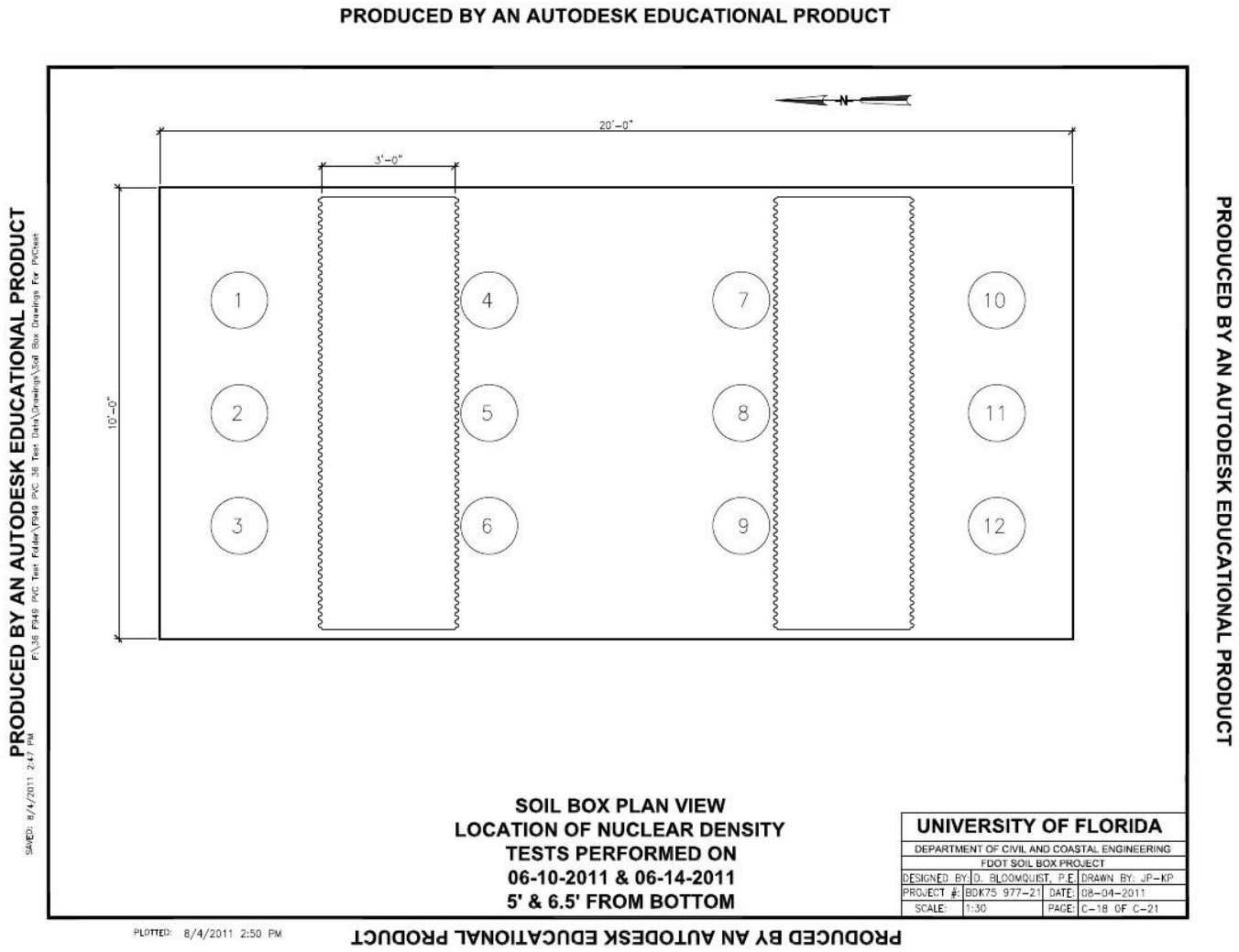

Figure 2-20. Plan view schematic showing the locations of nuclear density tests performed five feet and 6.5 feet from the bottom of the Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 31). University of Florida, Gainesville, Florida.]

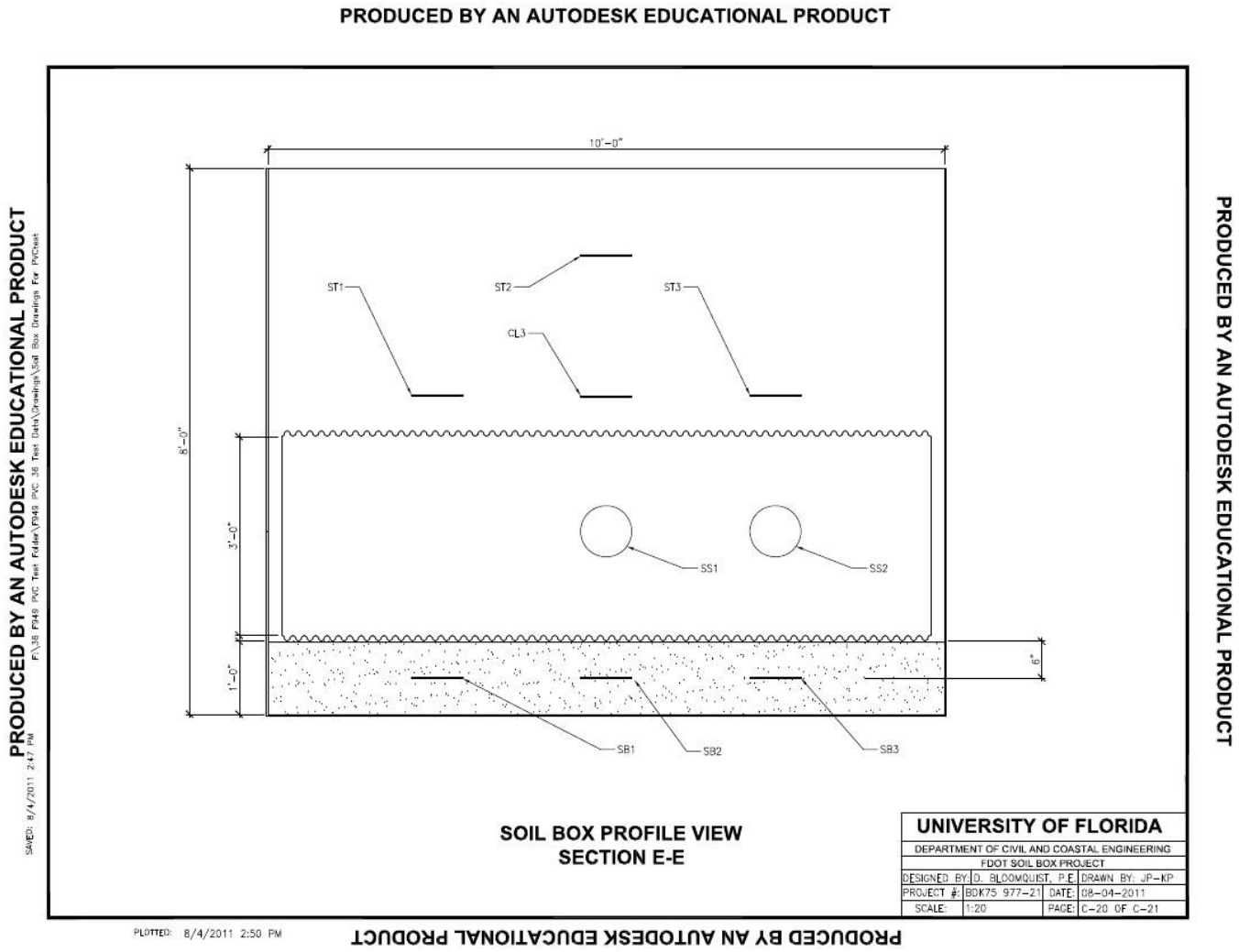

Figure 2-21. Profile view of Soil Box showing placement of earth pressure cells around the South pipe. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 35). University of Florida, Gainesville, Florida.]

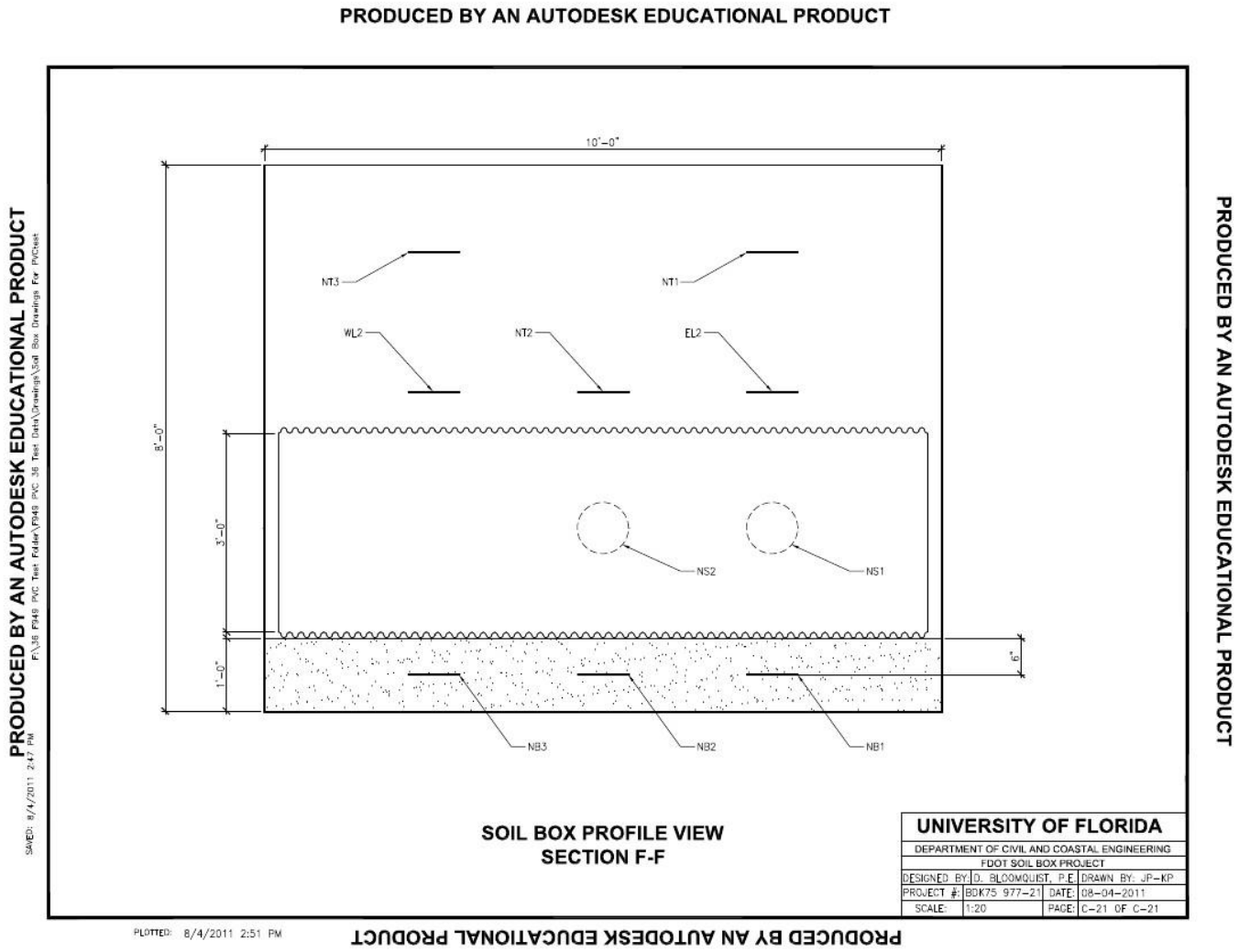

Figure 2-22. Profile view of Soil Box showing earth pressure cells placed around the North pipe. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 34). University of Florida, Gainesville, Florida.]

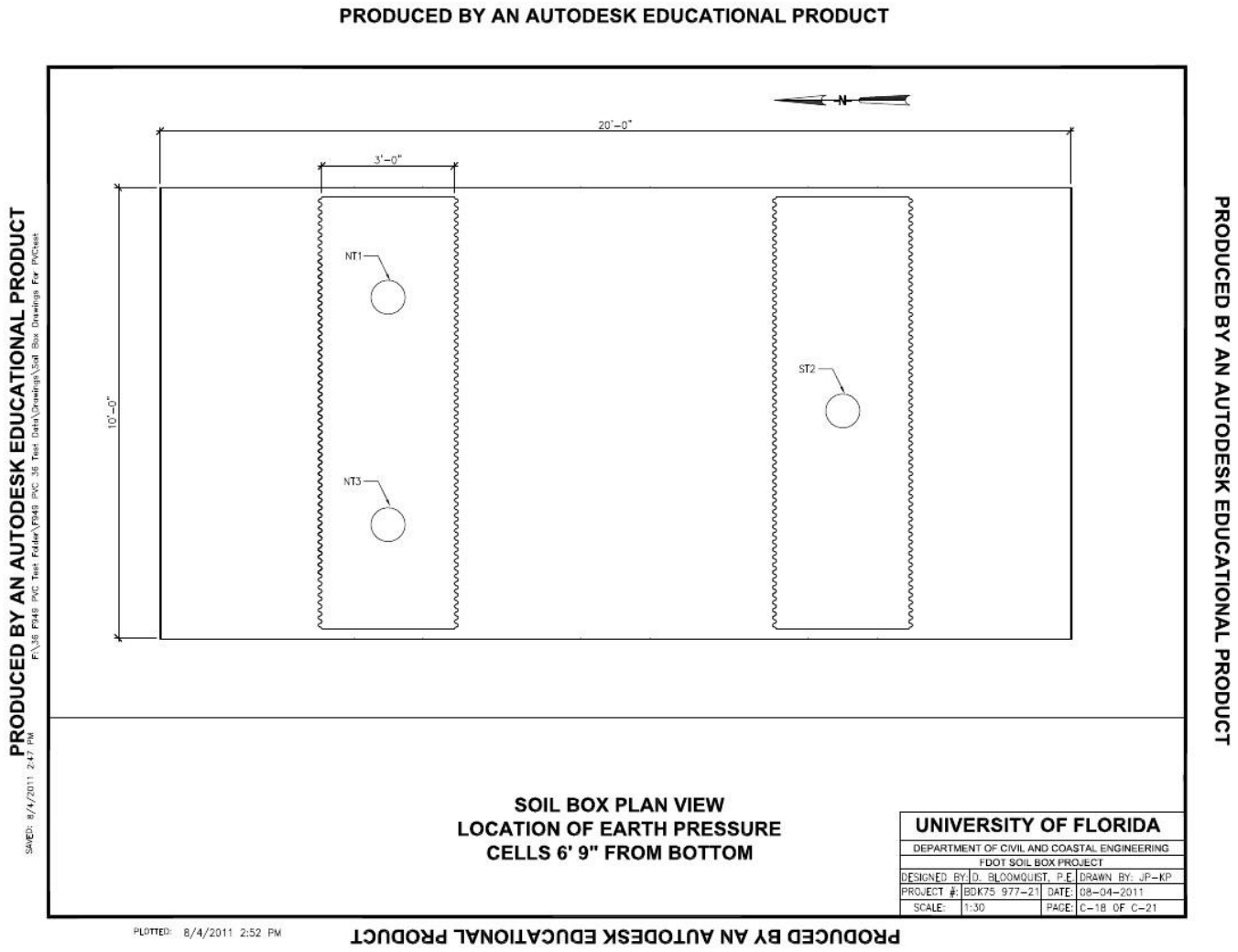

Figure 2-23. Plan view of Soil Box showing placement of earth pressure cells six feet nine inches from the bottom of the Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 39). University of Florida, Gainesville, Florida.]

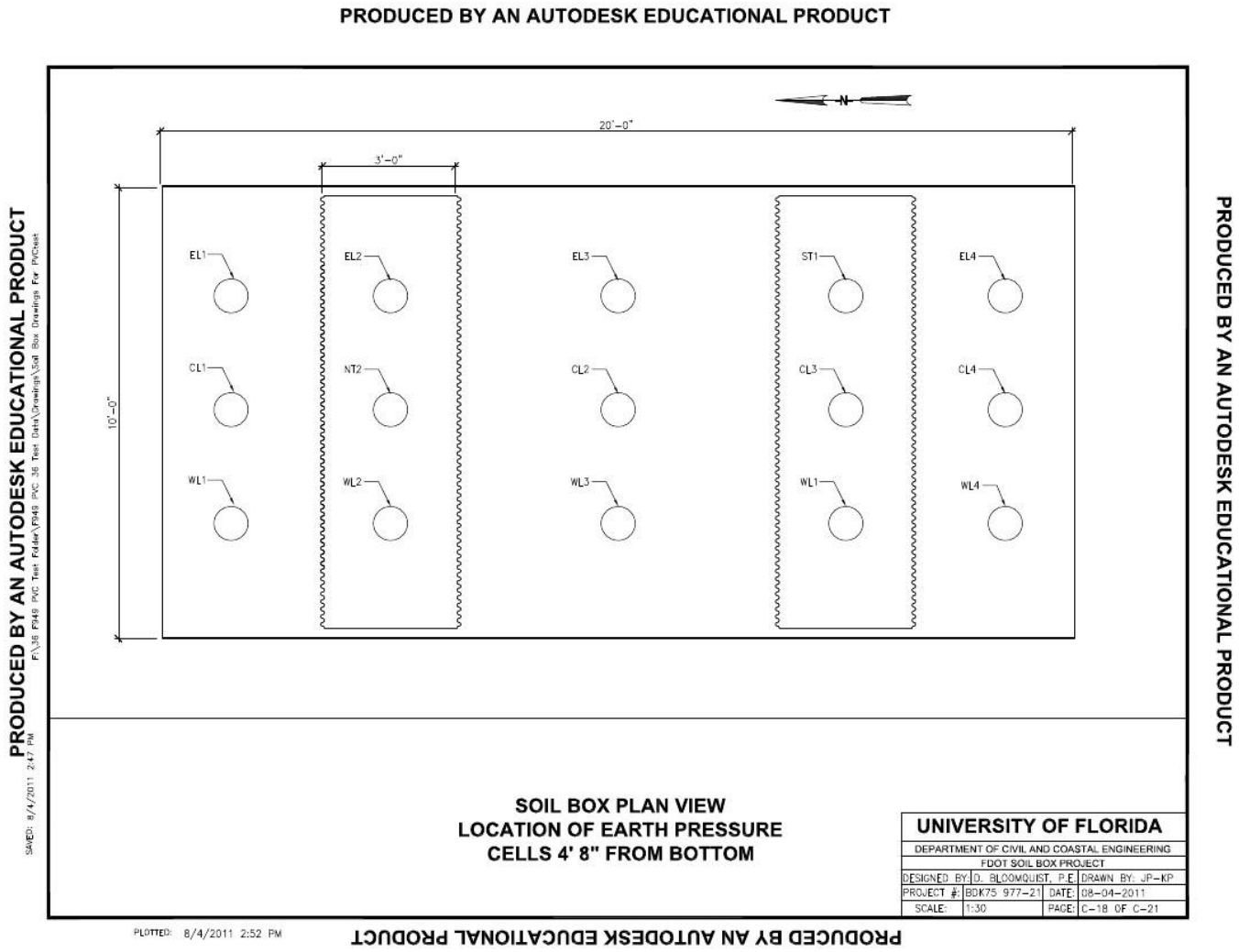

Figure 2-24. Plan view of Soil Box showing placement of earth pressure cells four feet eight inches from the bottom of the Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 38). University of Florida, Gainesville, Florida.]

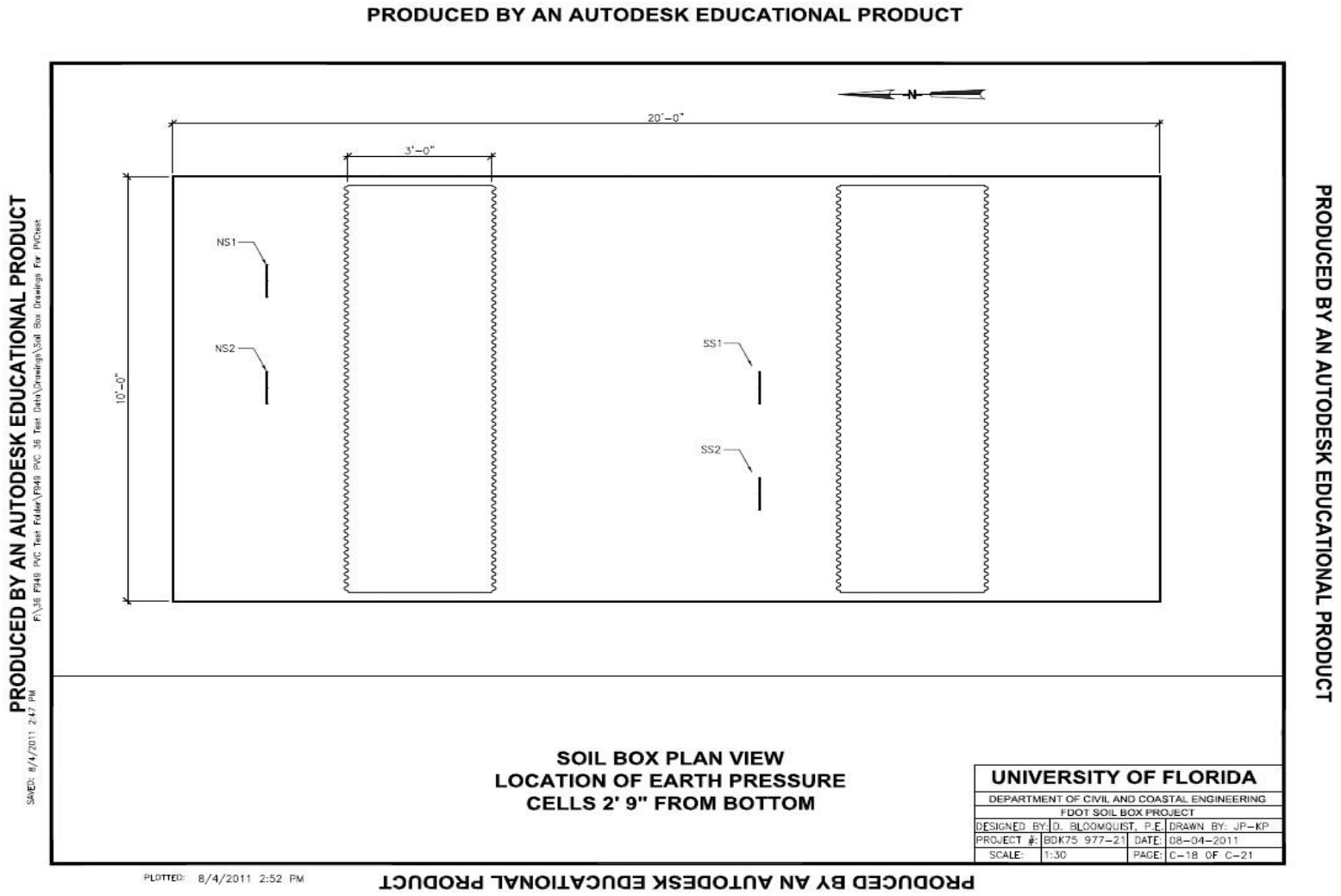

Figure 2-25. Plan view of Soil Box showing placement of earth pressure cells two feet nine inches from the bottom of the Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 37). University of Florida, Gainesville, Florida.]

Figure 2-26. Installation of earth pressure cells located eight inches above the pipes. Photo credit: Z. Faraone.

Figure 2-27. Soil being saturated with a lawn sprinkler. Photo credit: Z. Faraone.

Figure 2-28. Two small lift bags on one steel plate. Photo credit: Z. Faraone.

Figure 2-29. 10 pounds per square inch (PSI) being applied to lift bags to check fittings. Photo credit: Z. Faraone.

Figure 2-30. End section being hoisted onto Soil Box by lift truck. Photo credit: Z. Faraone.

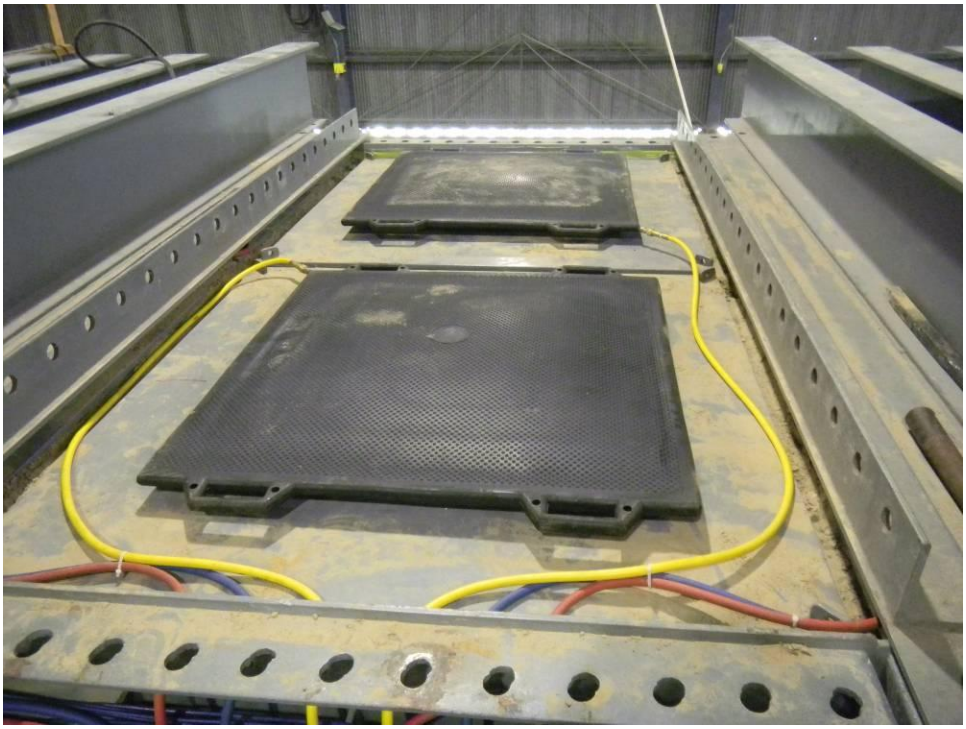

Figure 2-31. Top of Soil Box before middle top section is installed. Photo credit: Z. Faraone.

Figure 2-32. Laser mounting system installed into pipe. Photo credit: Z. Faraone.

Figure 2-33. Steel plate removal with fork lift. Photo credit: Z. Faraone.

Figure 2-34. Soil Box after North face removal. Photo credit: Z. Faraone.

Figure 2-35. Front end loader removing soil from box. Photo credit: Z. Faraone.

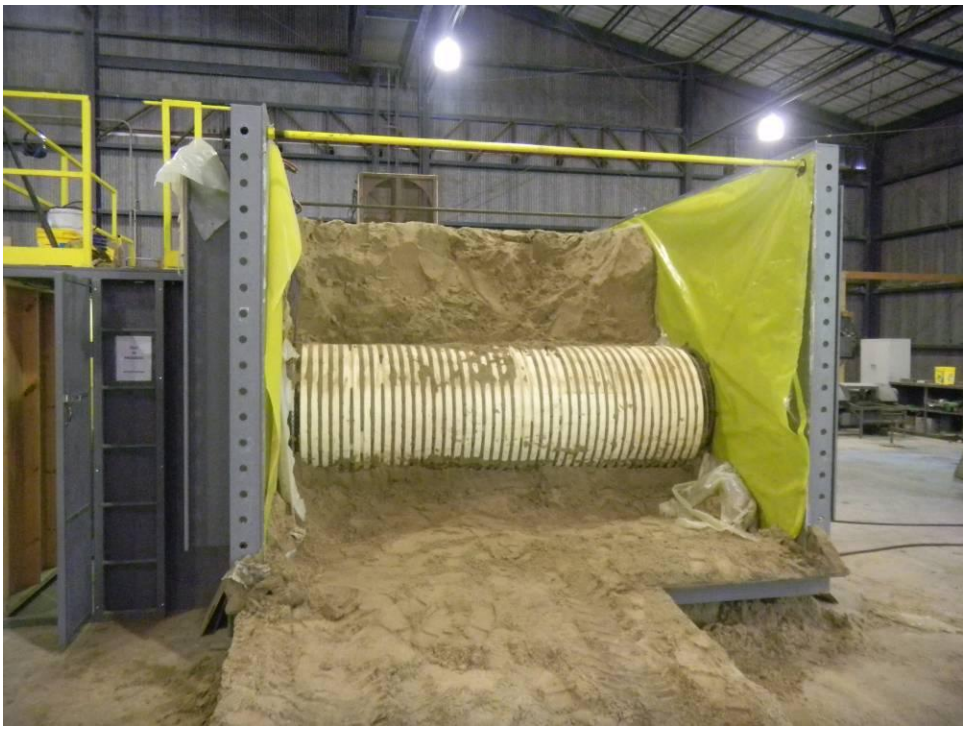

Figure 2-36. North pipe uncovered. Photo credit: Z. Faraone.

Figure 2-37. South pipe uncovered. Photo credit: Z. Faraone.

Figure 2-38. Soil Box finished being unloaded and ready to be prepared for next test. Photo credit: Z. Faraone.

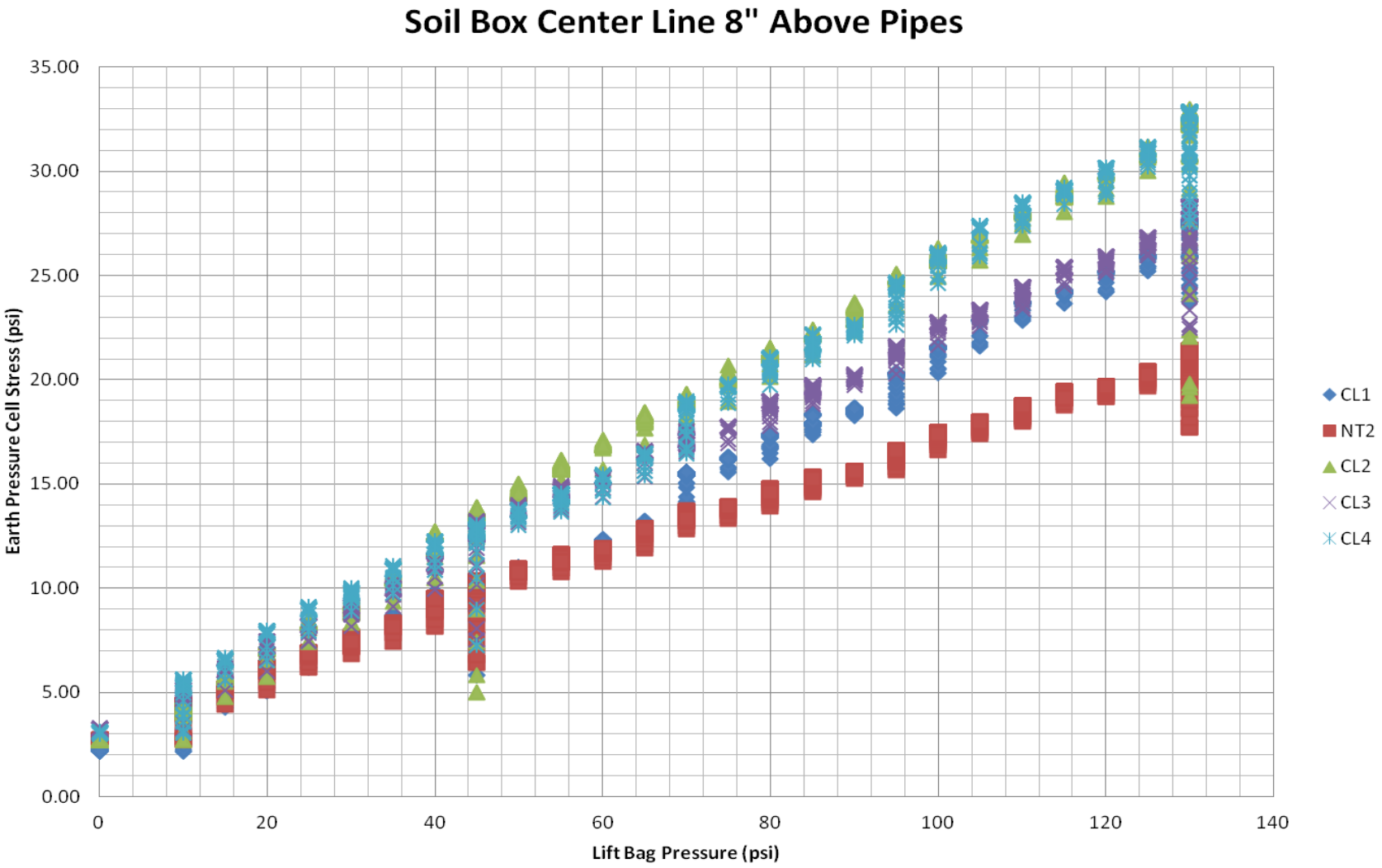

Figure 2-39. Plot of stress from earth pressure cells located eight inches above the pipes. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 45). University of Florida, Gainesville, Florida.]

Figure 2-40. Longitudinal crack sustained by South pipe during testing. Photo credit: Z. Faraone.

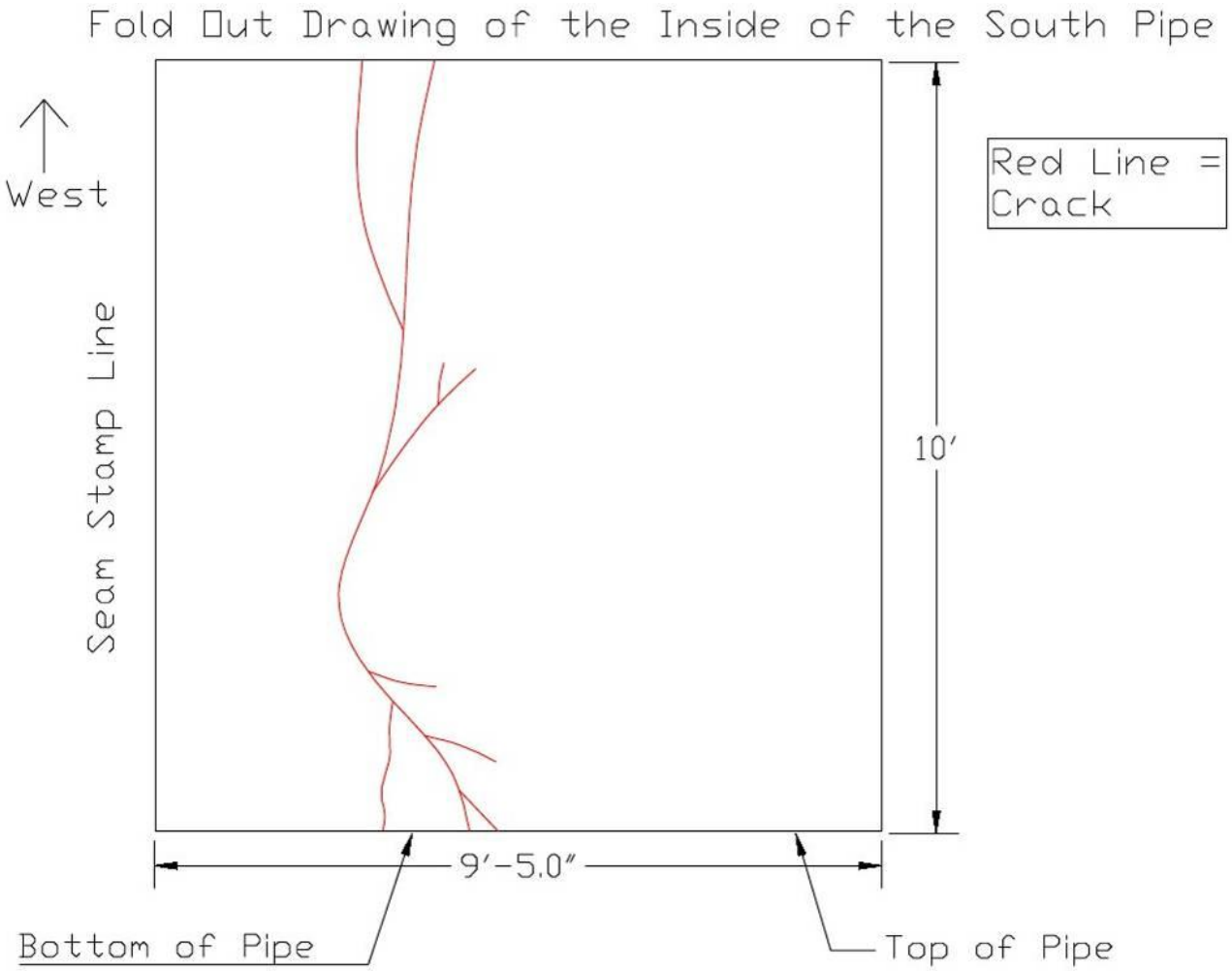

Figure 2-41. Fold out drawing of the longitudinal crack that occurred in the South pipe. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 49). University of Florida, Gainesville, Florida.]

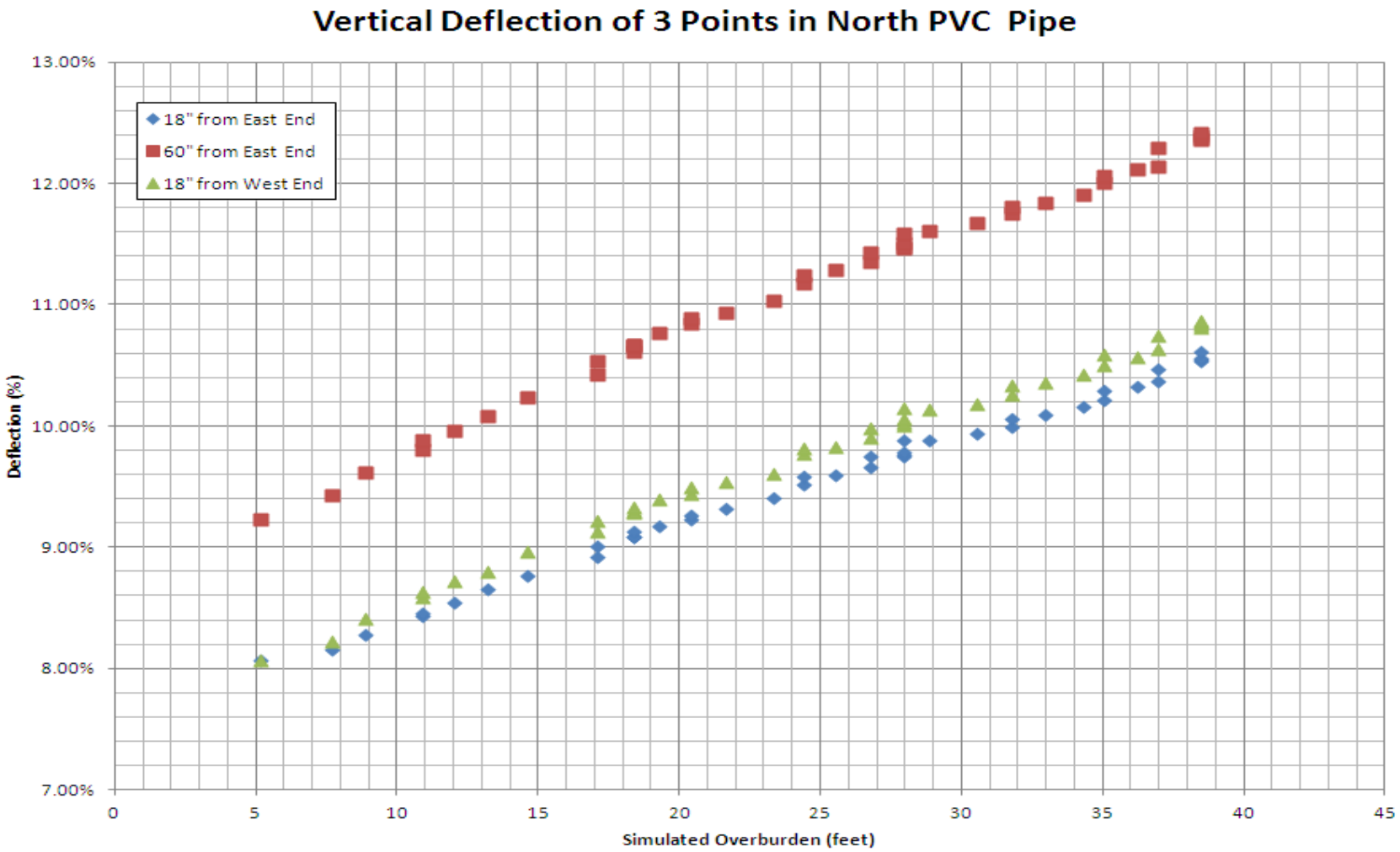

Figure 2-42. Plot of the deflection of three points located along the vertical diameter of the North pipe. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 46). University of Florida, Gainesville, Florida.]

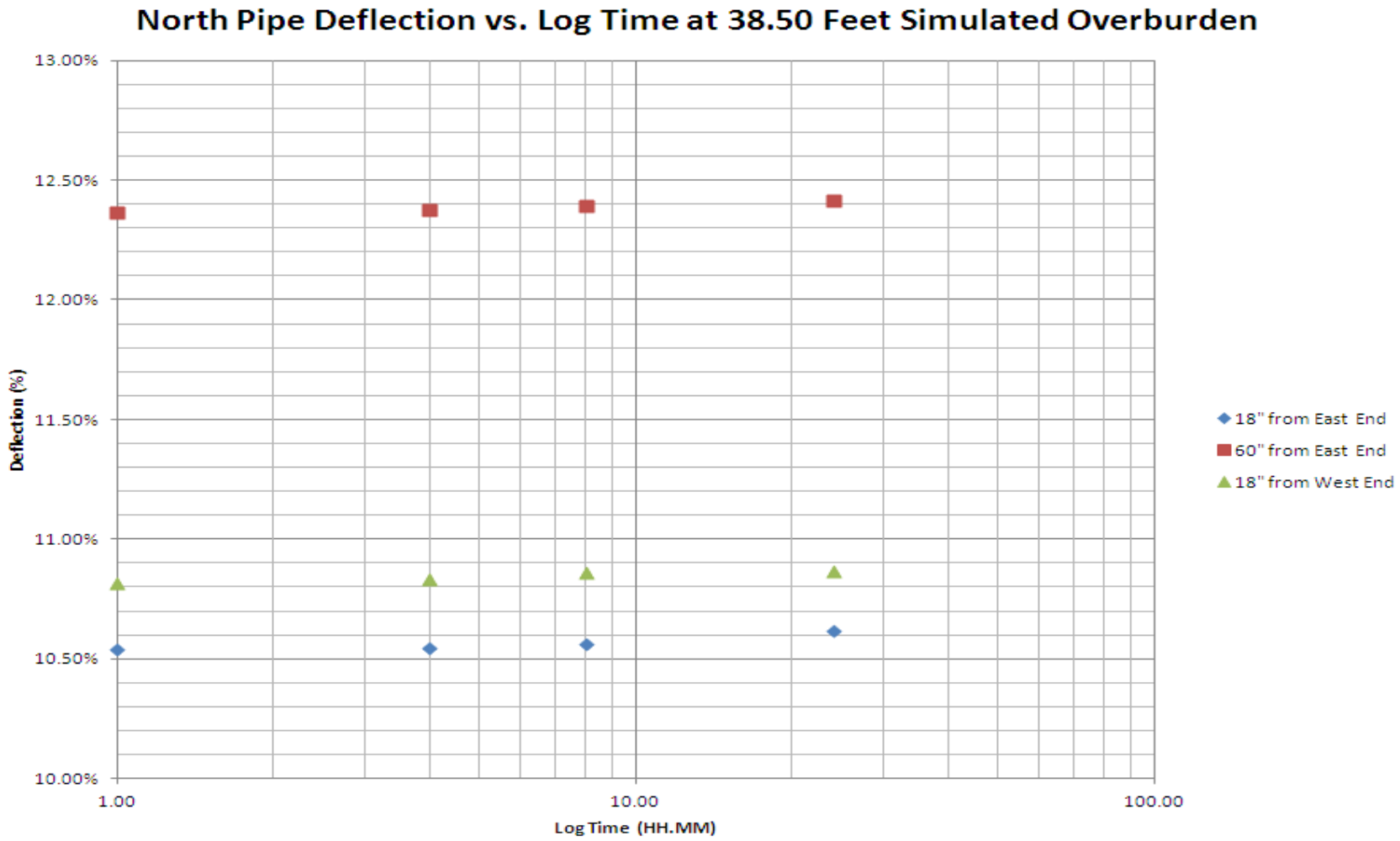

Figure 2-43. Plot of the deflection of the vertical diameter of the North pipe over a 24 hour period subjected to 38.5 feet of simulated overburden. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 8 (Page 47). University of Florida, Gainesville, Florida.]

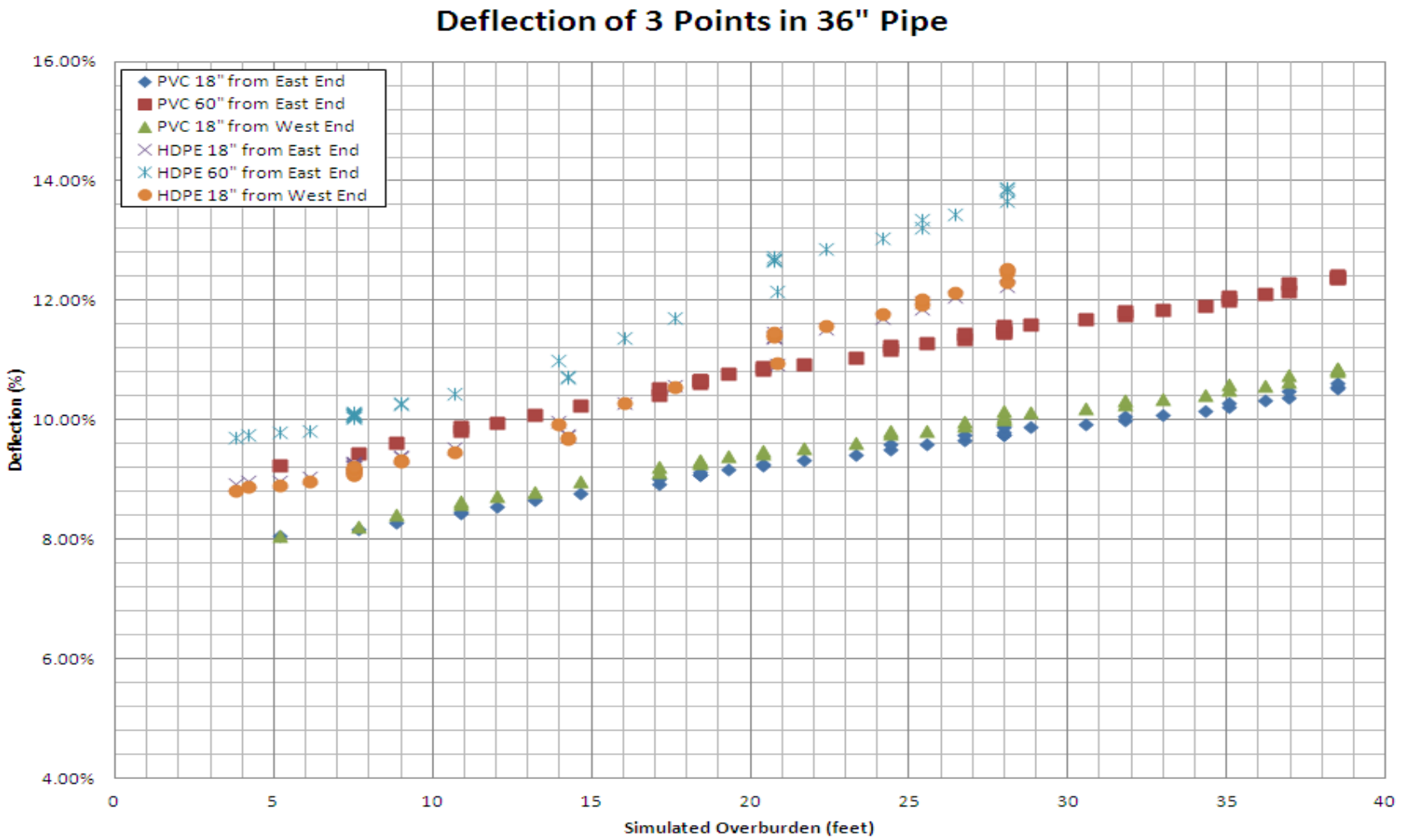

Figure 2-44. Plot comparing HDPE pipe test to PVC pipe test deflections.

CHAPTER 3
STEEL PIPE TEST WITHOUT TRENCH BOX

Pipe Preparation

The next test was performed on 36 inch flexible steel pipe. The pipes first had to be cut down to the appropriate length in order to fit into the box. This can be seen in Figure 3-1. Next they had to have steel rings installed onto each end to allow them to connect to the flexible membrane sealing system. Before and after pictures of the steel ring installation can be seen in Figure 3-2. These steel rings allow the rubber membrane to wrap around the pipes to keep soil from escaping the box out of the port holes while leaving plenty of room for the pipe to move freely. After the steel rings were installed on to the pipes the process of pre-deflecting them four percent was next.

One obstacle that was encountered when preparing the steel pipes for the next test was how to pre-deflect them. When pre-deflecting the PVC pipes the process required enhanced turnbuckles. With steel being the stiffest pipe to be tested it was unsure if it would be possible to pre-deflect them with the previous methods.

The first test to see if they would pre-deflect was on a 22 inch section. This is shown in Figure 3-3. This test involved only one turnbuckle and was successful.

The next trial involved a full sized section. During the deflection process the measurements taken at the ends of the pipe were much less than those taken in the middle of the pipe. It was obvious that the pipe was not deflecting at the outer ends beyond where the turnbuckles were located which can be seen in Figure 3-4. Also, during this trial it could be seen that kinking of the steel was occurring. This began the discussion on whether or not to pre-deflect the pipes and what methods could be used to more uniformly deflect them. In the end it was decided to increase the number of

turnbuckles from three to five and to extend the channels closer to the pipe ends. With these adjustments the pipes were successfully pre-deflected, as shown in Figure 3-5.

The steel pipe needed to be sealed at the ends where the steel rings meet the corrugation to keep the water from escaping during the saturation process. The sealing of the pipe ends can be seen in Figure 3-6. The pipes were now ready to be installed into the box.

Soil Box Preparation Modifications

A modification to the preparation was to the saturation process. The soil was saturated by using a lawn sprinkler to make sure the entire surface area of the top of the soil was reached. The sprinkler was left running all day and shut off at night. This process was done until approximately 17.5 hours of sprinkler time was logged. This was the point at which the saturation process was stopped for the previous tests on HDPE and PVC pipes. A nuclear density test was then done at nine locations throughout the Soil Box. The location of these tests can be seen in Figure 3-7. The moisture content was then given by these tests. With the moisture content the percent saturation was then calculated to be an average of 58.3%. According to the calculations for saturating the process should take around 34 hours. The moisture content was only taken 17.5 hours into the process to get an idea of the saturation of the soil during the other tests since they were stopped at this point.

With 100% saturation of the soil being the goal of this process the saturation continued. During this step the sprinkler was left on over night at one point and the water ended up coming out of the portholes of the box which is shown in Figure 3-8. After 50 hours density tests were done again in the same locations. The average percent saturation from those series of density tests ended up being 61.8%.

Since the saturation level of the soil only gained 3.5% after saturating for 32.5 hours more it was decided that in order to saturate the soil 100% it would take too much time and delay the project. Therefore this process was concluded with the soil being saturated at an average of 61.8% at one foot from the top of the soil level.

In order to saturate the soil 100% the flexible membrane sealing system for the pipes will need to be adjusted to be more watertight as well as the Soil Box itself being sealed better to minimize any leaks at the connections. Flooding around the box from the leaks can be seen in Figure 3-9.

A modification to the loading mechanism was put in place during this test. The individual regulators for the lift bags on each steel plate were installed. There are a total of ten individual regulators as shown in Figure 3-10. Four of the regulators go to two small lift bags each on the small steel plates. Six of the regulators go to one large lift bag each on the large steel plates. These individual regulators were installed to help provide a more uniform distribution of simulated overburden throughout the box by controlling the pressure in each lift bag.

With the turnbuckles removed from the pipes it was now possible to install the laser profiling system into each pipe. The laser profiling system was then checked to make sure everything was working properly. During this check it was apparent that there were errant readings from the laser at random points in the pipes. The problem was thought to be due to the reflectivity of the steel pipe. One point that was giving false readings was then sprayed with a red flat primer spray paint to reduce the reflectivity. This showed immediate positive results as the laser then gave a normal reading at that point. The four quadrants were then painted with a grey primer as shown in Figure 3-11.

After the primer dried over night the laser readings were checked again. The results from the grey primer showed errant readings from the laser still. The grey lines were then painted over with the red spray paint as shown in Figure 3-12. This fixed the problem completely in both pipes. Figure 3-13 shows a pipe with the laser profiling system installed. The Soil Box was now ready for testing.

Testing Modifications

The loading of simulated overburden for this test was done in a different fashion than the previous tests. The loading was controlled by the readings received from an array of 15 pressure cells located at a depth eight inches above the pipes in the Soil Box. The location of these cells can be seen in Figure 3-14.

The load was increased in five PSI increments in a main regulator that feeds the six individual regulators controlling the lift bags on the large steel plates. The individual regulators were then increased until the pressure readings from the 15 cells located at a depth eight inches above the pipes were fairly equivalent. Another main regulator that feeds the individual regulators that control the lift bags on the small steel plates was also increased at the same time to help get an even reading from all of the 15 cells.

This process was continued until 130 PSI was reached in the main regulator feeding the large lift bags. 130 PSI was chosen because it is the maximum amount of pressure the lift bags can sustain without failure. At this point only one lift bag was receiving the full 130 PSI in order to keep the pressure even throughout the cells. This meant that all the other bags weren't at the full amount of pressure they could receive. Since the lift bag with the maximum amount of pressure was over the North pipe it was decided that the other lift bags would be increased according to the two lift bags over the South pipe. The two lift bags were at approximately 60 PSI when the maximum

pressure had been received in the other lift bag. To save time the pressure in the two bags over the South pipe were increased in 20 PSI increments and one final 10 PSI increment to get to the maximum 130 PSI. After the two bags over the South pipe were increased by one increment of 20 PSI the other lift bags were increased until the pressure readings from the cells were as even as possible.

During the loading sequence the load was held for one hour and then deflection readings were taken. For one-third and two-thirds of the total increments the load was held and deflection readings were taken at one hour, four hours, and eight hours. During the final load increment deflection readings were taken at one hour, four hours, eight hours, and 24 hours after the load was applied. The readings were taken at these time increments to show how the pipes were deflecting over time. Table 3-1 shows the loading increments, deflection readings timing and simulated overburden.

A final addition to the procedure was to measure the deflection in the soil. This was done the same way it was done for the calibration test. Small steel plates were placed in the soil at locations near the tops of the pipes. These plates were attached to string potentiometers. As the load was applied the small steel plates moved with the soil. The movement of these plates was recorded into a computer program. This data provides a deflection reading which will ultimately be used in calculating the strain in the soil. This data will be used for the finite element analysis. Soil deflection data were acquired for both the loading and unloading sequences.

Results

After a full loading sequence was applied using the individual regulators it was shown that there were some obstacles to overcome with the loading mechanism. As was stated earlier the pressure increase in each individual bag is controlled by an

individual regulator. The individual regulators are then increased in steps to achieve a uniform distribution of stress throughout the Soil Box. With this technique only one individual regulator received the maximum amount of pressure which limited the amount of simulated overburden.

The other regulators received less pressure because they didn't need as much force to achieve the same pressure reading in the cell beneath it as the other lift bag did. The deflection readings from the pipes though showed that something else was happening. The lift bag receiving the most pressure was located above the West side of the North pipe. The deflection of the North pipe showed it was deflecting more in the West than in the East. Also, the overall deflection of the North pipe was more than that of the South pipe. This would seem to point out that the readings from the pressure cells were not accurate during the testing.

It was concluded that the earth pressure cell that was being used to control the loading process was giving lower readings than the actual load being applied. Therefore the North pipe received more load than the South pipe in the beginning causing the rate of loading to differ between the two pipes.

To clarify the results from the steel pipe test one more steel pipe will be tested along with one HDPE pipe with trench box installation as originally scheduled. To get a more accurate pressure reading new cells were acquired. These cells will be installed a half inch above the pipe. There will be three cells placed on each pipe. These will give the reading of the soil pressure directly on top of the pipes.

Overall, the North pipe ended up reaching a deflection of around 8.5% at a simulated overburden of 36 feet. It reached 5% deflection at the beginning of the test.

Figure 3-15 shows the plot of percent deflection versus simulated overburden for the North steel pipe as well as the PVC and HDPE pipes for comparison. Steel shows the same behavior as PVC during testing.

Table 3-1. Loading sequence and deflection readings for steel pipe test.

Pressure Applied to Main Regulator (PSI)	Deflection Readings taken x hours after pressure was applied	Simulated Overburden Over Pipes (feet)
0	1	3.32
5	1	3.46
10	1	3.69
15	1	5.28
20	1	6.32
25	1	7.52
30	1	7.83
35	1	8.94
40	1	9.92
45	1, 4, 8	10.29
50	1	10.71
55	1	11.31
60	1	12.60
65	1	12.86
70	1	13.39
75	1	14.45
80	1	15.28
85	1	16.01
90	1, 4, 8	16.66
95	1	17.87
100	1	18.14
105	1	18.68
110	1	19.35
115	1	20.27
120	1	20.75
125	1	21.32
130	1, 4, 8, 24	22.02
130 (80)	1	28.48
130 (100)	1	32.79
130 (120)	1	36.22
130 (130)	1	36.65

The numbers in parentheses indicate the increment increased in lift bags over the South pipe.

Figure 3-1. Steel pipe being cut down to fit into Soil Box. Photo credit: Z. Faraone.

A

B

Figure 3-2. Steel pipe modification. A) Steel pipe before steel ring installation. B) Steel pipe after steel ring installation. Photo credit: Z. Faraone.

Figure 3-3. Successfully pre-deflected steel pipe section. Photo credit: Z. Faraone.

Figure 3-4. First attempt to pre-deflect steel pipe showing end not deflecting as much as the middle. Photo credit: Z. Faraone.

Figure 3-5. Steel pipe successfully pre-deflected. Photo credit: Z. Faraone.

Figure 3-6. Steel pipe sealing. Photo credit: Z. Faraone

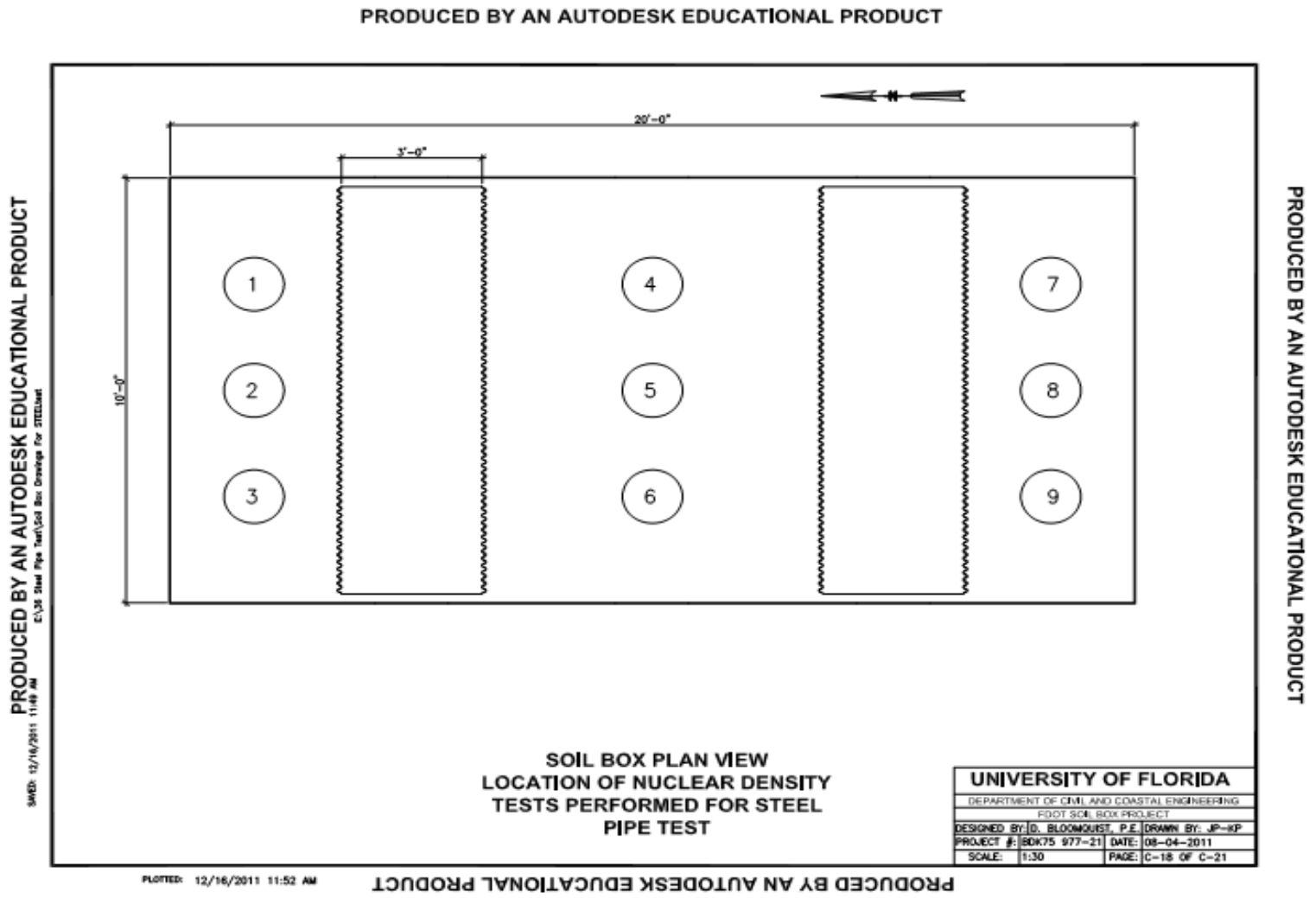

Figure 3-7. Location of nuclear density tests performed during filling and saturation of Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 9 (Page 22). University of Florida, Gainesville, Florida.]

Figure 3-8. Water flowing out of portholes during saturation process. Photo credit: Z. Faraone.

Figure 3-9. Flooding around Soil Box during saturation process. Photo credit: Z. Faraone.

Figure 3-10. Individual regulators installed to help improve load distribution. Photo credit: Z. Faraone.

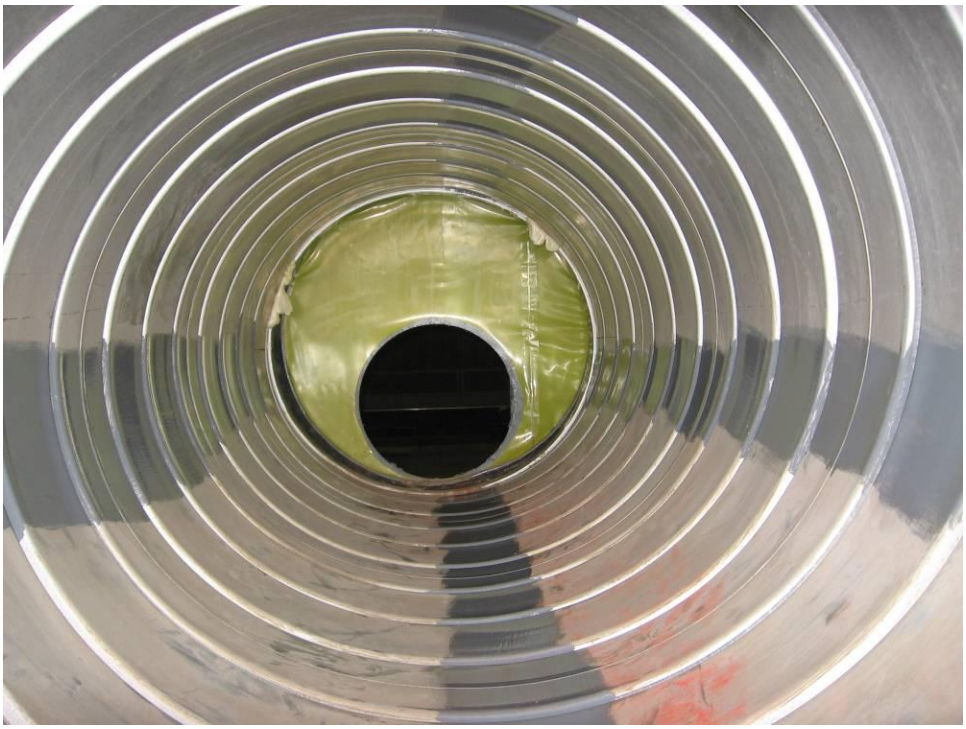

Figure 3-11. First attempt at reducing laser reading errors with grey primer. Photo credit: Z. Faraone.

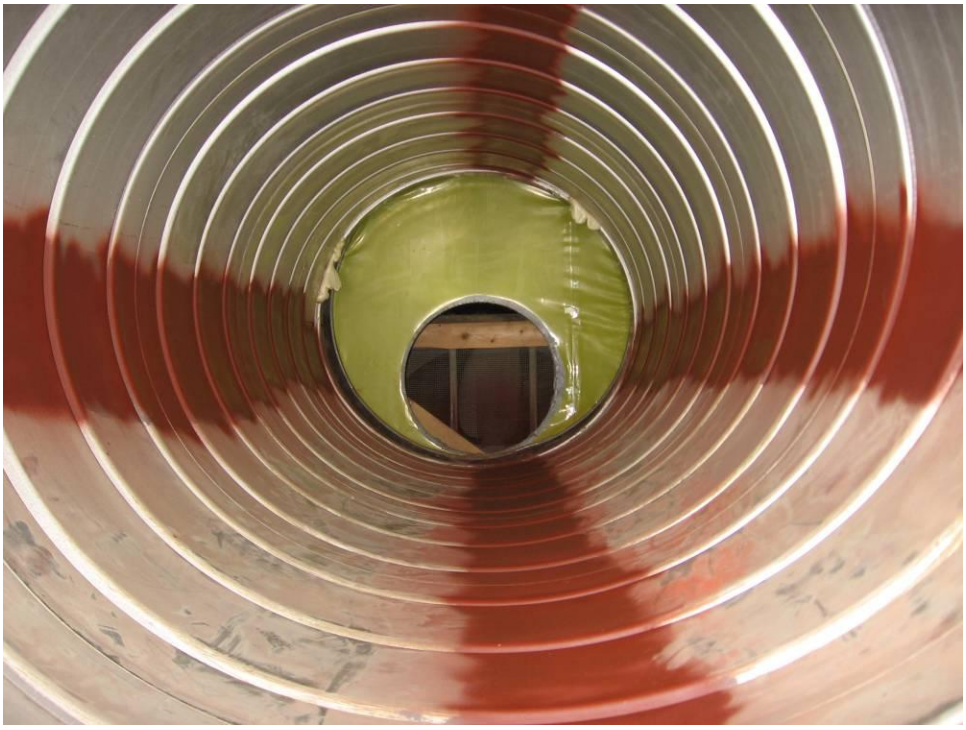

Figure 3-12. Steel pipe painted with red primer to stop laser reading errors. Photo credit: Z. Faraone.

Figure 3-13. Steel pipe with laser profiling system installed ready for testing. Photo credit: Z. Faraone.

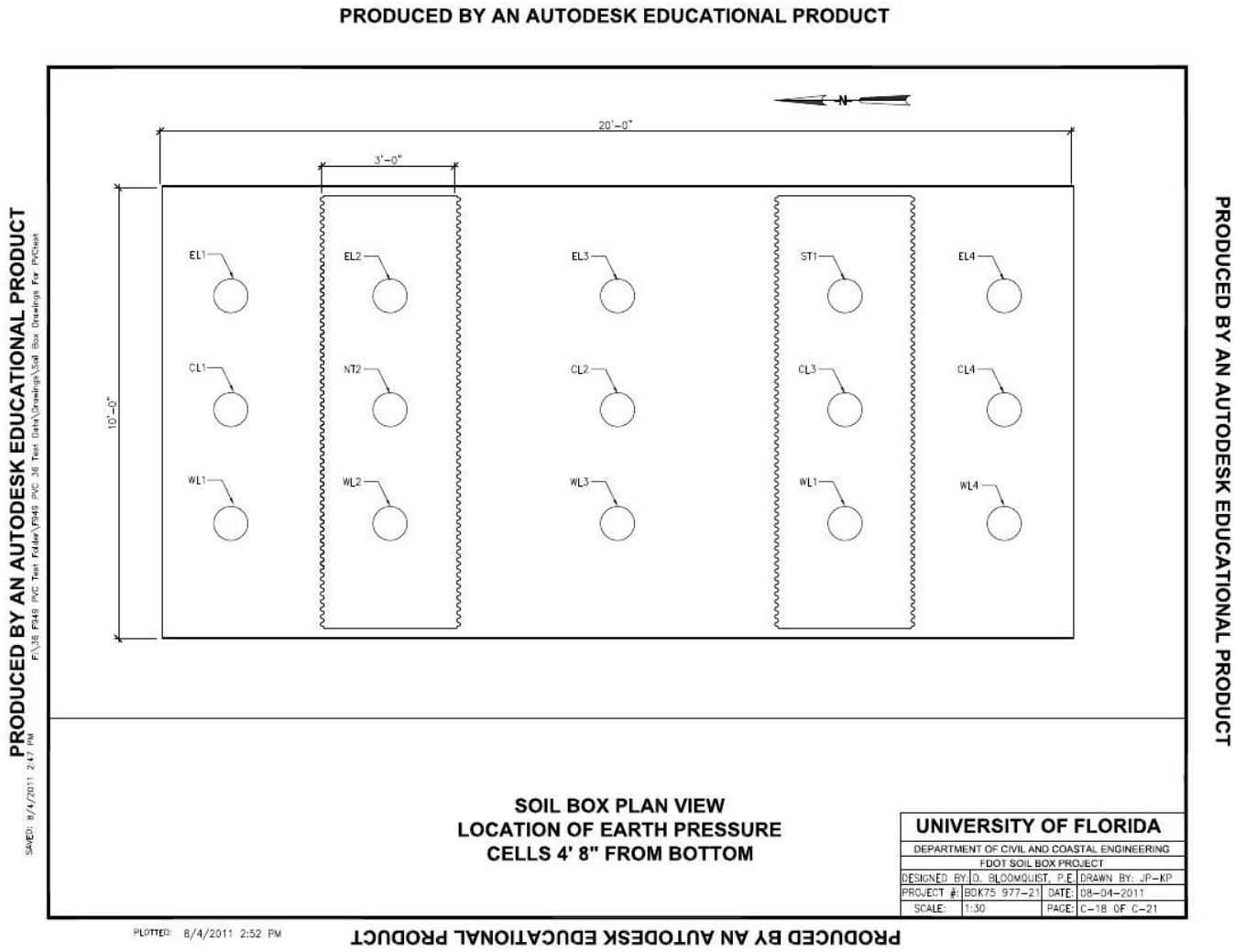

Figure 3-14. Plan view of earth pressure cells located eight inches above the pipes that are you used to control the loading increments. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 9 (Page 30). University of Florida, Gainesville, Florida.]

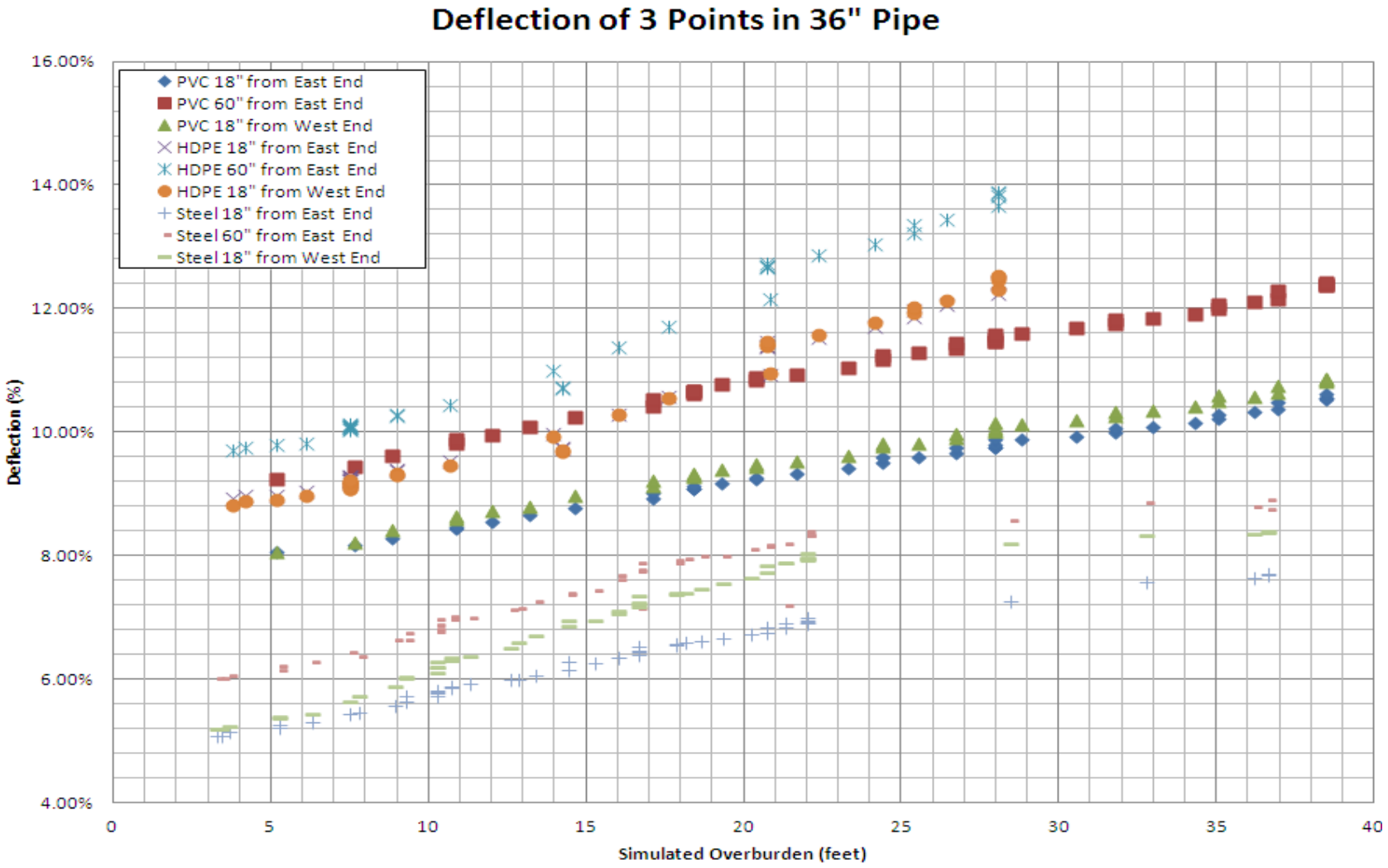

Figure 3-15. Plot of percent deflection versus simulated overburden comparing steel, PVC, and HDPE pipes.

CHAPTER 4
STEEL PIPE WITHOUT TRENCH BOX AND HDPE PIPE WITH TRENCH BOX TEST

Trench Box Purpose

The trench box is used when the trench is at depths that are too great to have the soil walls support themselves. This safety issue calls for the use of a box to support the walls of the trench.

The box is put in place and excavation continues. Once the correct depth is achieved the pipe is installed. After installation the trench is backfilled and then the box is pulled forward for the next section of the pipeline. The process of pulling the box forward causes a volume of soil to have a lower density. When a flexible pipe is buried in the soil, the pipe and soil then work as a system in resisting the load (Moser, 2001). As the pipe deflects it develops the passive forces in the soil and if these forces are low due to a low density then this system will work poorly.

Therefore a test on the most backfill sensitive pipe, HDPE, is being done with this installation technique. At the conclusion of the test the results will be compared to the pipes tested without this installation technique to see if there is a difference.

Trench Box Design and Fabrication

Since the Soil Box isn't exactly 10 feet wide at all locations the ability to use an already made trench box that would fit into the box wasn't feasible. This meant one needed to be fabricated at the Coastal Engineering Laboratory.

After reviewing many different types of trench boxes and the different standards that they are made by the dimensions were chosen. According to the American Association of State Highway and Transportation Officials (AASHTO) a trench box for a 36 inch diameter pipe should be 73 inches wide (The Plastic Pipe Institute, 2011). This

dimension was used for the inside distance between the box walls. The next dimension that was in question was the thickness of these walls. The FDOT uses boxes with thicknesses of 4 inches, 6 inches, and 8 inches. It was decided to use the dimension of 8 inches because it would have the largest affect on the density of the soil around the pipe.

With the dimensions chosen the box was then designed accordingly. A frame was made from six inch steel channel. The frame was then painted to keep from rusting. The painted frames can be seen in Figure 4-1. To make up the extra two inches, three-quarter inch plywood was screwed to each side of the frame. A half inch spacer was placed between the frame and one side of the plywood. The plywood was painted on the edges to prevent moisture from entering. The plywood was then lacquered on both sides to keep it from rotting. The frame with one side of plywood can be seen in Figure 4-2. This sealing will allow the trench box to keep on being reused without using more plywood. Once each wall was constructed they were connected with four steel pipe braces. The trench box was now ready for installation into the Soil Box. The completed trench box can be seen in Figure 4-3.

Soil Box Preparation Modifications

Since the soil was only able to achieve 61% saturation during the previous test different measures were taken to increase the saturation for the next test. During the saturation the Soil Box was leaking from many different areas. Once the box was emptied the seal was inspected and it was decided that it should be resealed. A marine grade sealant was used to go over the old sealant. The resealed box can be seen in Figure 4-4. The steel rings used for the flexible membrane sealing system were also sealed onto the wall with the same sealant to help prevent leaking from the portholes.

With the addition of the trench box to this test the cables for the cells had to be rerouted. The cables were rerouted so that they would not be crushed by the box walls. This meant some of the cables had to be buried before they were installed into the Soil Box. The rerouted cables can be seen in Figure 4-5.

The trench box was installed by using the lift truck to hoist the box over the North end of the Soil Box. This can be seen in Figure 4-6. It was then lowered and placed over the HDPE pipe. A picture of the trench box installed can be seen in Figure 4-7. After two lifts of soil were added the cross bars were removed in order to allow the walls to be removed individually at the final soil height. The friction of the soil on the walls would be too much force to overcome for the lift truck with both walls at the same time. Before, during and after removal of the trench box walls can be seen in Figures 4-8, 4-9 and 4-10.

Due to the addition of the trench box the location of nuclear density tests and placement of earth pressure cells were slightly changed. Density tests were done at each lift as shown in Figures 4-11, 4-12, and 4-13. The cells were placed while soil was added according to the drawings shown in Figures 4-14, 4-15, 4-16, 4-17, 4-18, 4-19, and 4-20. These locations are almost the same as the locations of the cells during the steel pipe test with the addition of the new small cells. A picture of the addition of the new instrumentation can be seen in Figure 4-21.

Once the trench box walls were removed the voids left by this removal were filled with soil. The soil was now ready to be saturated.

In order to try and achieve 100% saturation the drain for the Soil Box was closed. This allowed more water to be retained by the soil. After watering for around 28 hours it

was noticed that water and soil were coming out of the North-West porthole. At this time the drain was opened to allow the water to exit from another opening. After returning to the lab after the weekend much more soil had exited through the porthole. A void formed going from the top of the soil to the porthole exit. Figures 4-22 and 4-23 show the void from the top of the Soil Box.

This is believed to have been caused by the rising water table from having the drain closed. The drain was closed to help achieve 100% saturation by retaining more water. Once the water table was high enough the pressure caused the flexible membrane to be pushed through and the soil water mixture ended up being dispersed through this porthole. This mixture can be seen in Figures 4-24 and 4-25.

To allow the test to continue this void had to be filled. First the seal between the pipe and the wall needed to be modified. An inner tube was inflated inside the pipe at this connection to seal it since the flexible membrane had failed. Then the void was filled. Saturation then continued for another six hours to reach 34 hours, this time the drain was left open.

A final addition to the preparation was adding chain link fence to the loading mechanism. Before the steel plates were placed on top of the soil the fencing was placed as shown in Figure 4-26. The purpose of this is to help distribute the load more evenly by allowing the plates to settle at the same rate.

Testing Modifications

The loading sequence was controlled by the six pressure cells located just above the pipes. During the testing the cells showed that the West side was receiving more pressure than the East side. The individual regulators were then adjusted to allow more pressure to be applied to the East lift bags over the pipes. As the increments were

applied the deflection data were being analyzed to see how the pipes were deflecting. Once the pipe movements evened out the pressure in all the lift bags was returned to the same. Table 4-1 shows the loading increments, deflection readings timing and simulated overburden.

During the loading sequence there was a failure in one of the large lift bags. This lift bag was located over the West end of the South pipe. This failure occurred at the 125 PSI increment that was being held over the weekend. When returning to the lab it could be heard that a lift bag was leaking air. The pressure had dropped in the large bags from 125 PSI to 60 PSI. It was then decided to stop the flow of air to the faulty lift bag and restore air the air pressure back 125 PSI. The test then continued as normal.

Results

The HDPE pipe with trench box installation showed the greatest deflections of the research project. During the loading sequence it showed signs of failure with bubbles appearing in the inside of the pipe. These can be seen in Figure 4-27. At the beginning of the loading sequence the deflection was around 10.25%. At the end it reached nearly 18% with 20 feet of overburden. Figure 4-28 shows the deflection of the pipe versus simulated overburden for three points in the pipe. This plot has an upward trend which could mean the rate of deflection was increasing with the application of more overburden. Figure 4-29 is a graph of the deflection at a depth of 19.83 feet over a 24 hour period. The pipe appears to be continually creeping over this time.

The steel pipe began the loading sequence around 4.5% deflected and ended with around 7% at 35 feet of overburden. A plot of the results from this sequence can be seen in Figure 4-30. When comparing the results to the previous test with steel pipes

the rate of deflection was very similar to the rate of the North pipe during the previous test. Figure 4-31 shows the two pipes plotted on the same graph.

In conclusion, the HDPE with trench box installation data showed the installation technique had a huge affect on the performance of the pipe. The steel pipe results from the first test were verified with the data from this test.

Table 4-1. Loading sequence and deflection readings for high density polyethylene (HDPE) with trench box and steel pipe test.

Pressure Applied to Main Regulator (PSI)	Deflection Readings taken x hours after pressure was applied	Simulated Overburden Over HDPE Pipe (feet)	Simulated Overburden Over Steel Pipe (feet)
0	1	4.44	4.33
5	1	5.16	5.17
10	1	6.64	6.72
15	1	8.15	8.39
20	1	9.29	9.77
25	1	9.98	10.66
30	1	9.57	11.16
35	1	11.33	12.73
40	1	12.01	13.17
45	1, 4, 8	12.37	14.26
50	1	12.66	14.85
55	1	14.3	15.85
60	1	15.17	16.54
65	1	16.41	18.5
70	1	17.18	20.40
75	1	14.69	23.17
80	1	16.66	26.32
85	1	18.03	27.55
90	1, 4, 8	17.44	28.32
95	1	17.68	29.34
100	1	18.68	30.54
105	1	18.02	31.38
110	1	18.91	32.51
115	1	19.76	33.85
120	1	18.87	34.55
125	1	19.61	35.59
130	1, 4, 8, 24	19.83	24.64

Figure 4-1. Painted trench box frames. Photo credit: Z. Faraone.

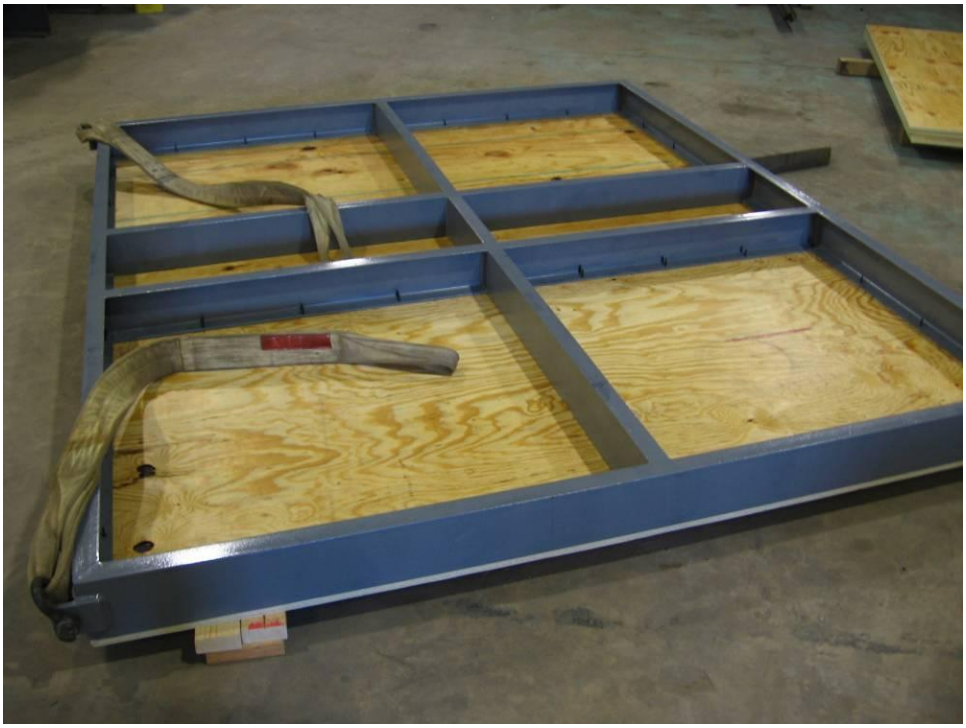

Figure 4-2. Trench box wall with one side of plywood. Photo credit: Z. Faraone.

Figure 4-3. Completed trench box. Photo credit: Z. Faraone.

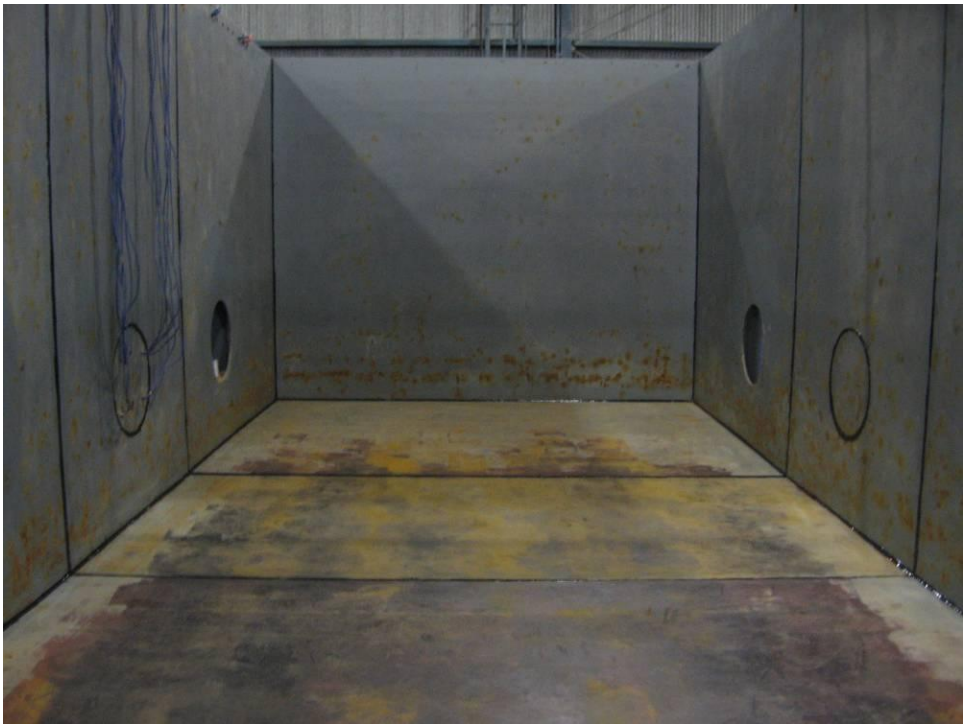

Figure 4-4. Resealing of Soil Box. Photo credit: Z. Faraone.

Figure 4-5. Rerouting of earth pressure cell cables to avoid trench box walls. Photo credit: Z. Faraone.

Figure 4-6. Trench box being hoisted into Soil Box by lift truck. Photo credit: Z. Faraone.

Figure 4-7. Trench box successfully placed into Soil Box. Photo credit: Z. Faraone.

Figure 4-8. Trench box walls before removal. Photo credit: Z. Faraone.

Figure 4-9. Trench box wall being removed by lift truck. Photo credit: Z. Faraone.

Figure 4-10. Voids left after trench box removal. Photo credit: Z. Faraone.

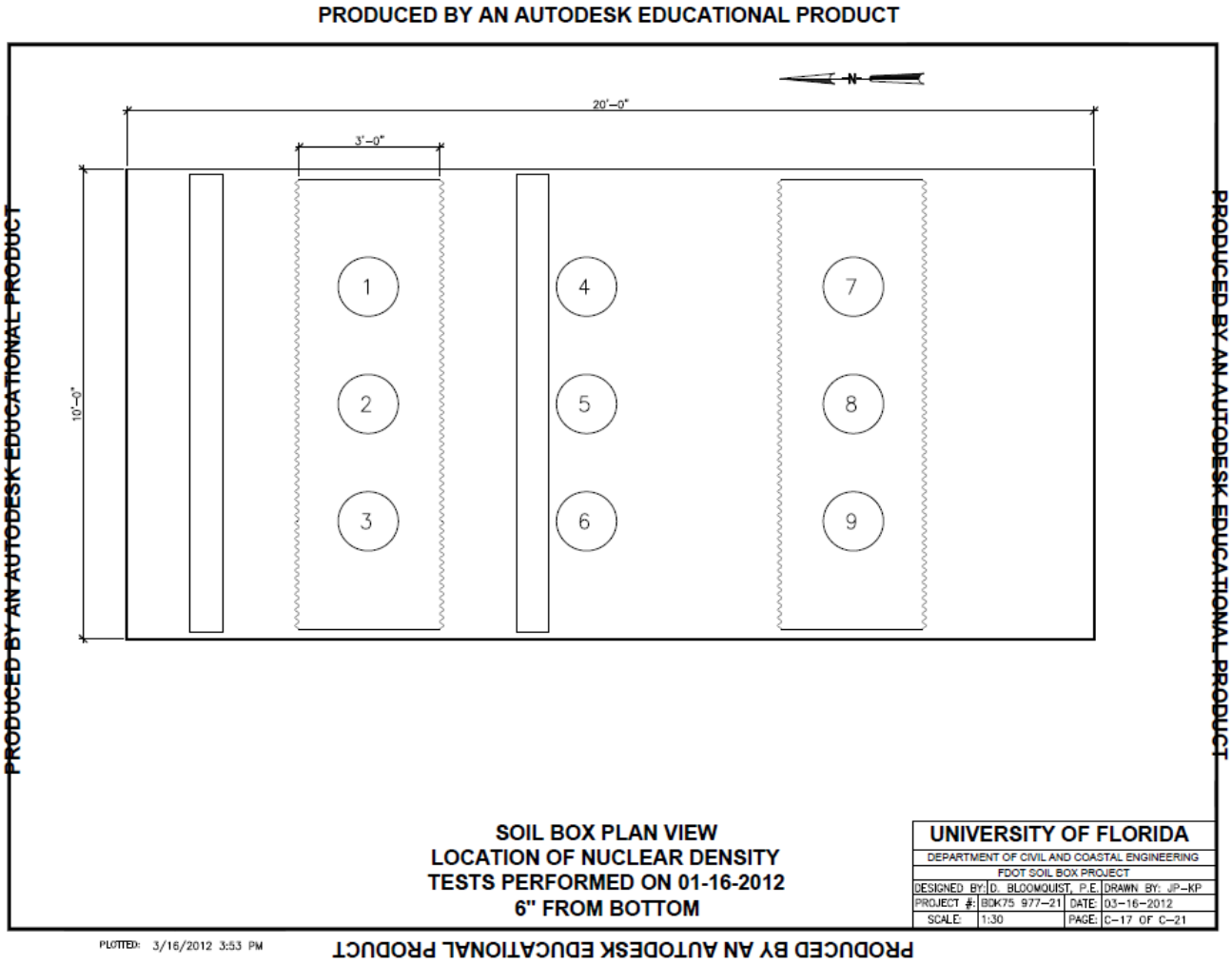

Figure 4-11. Plan view of locations of nuclear density tests six inches from bottom of Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 10 (Page 27). University of Florida, Gainesville, Florida.]

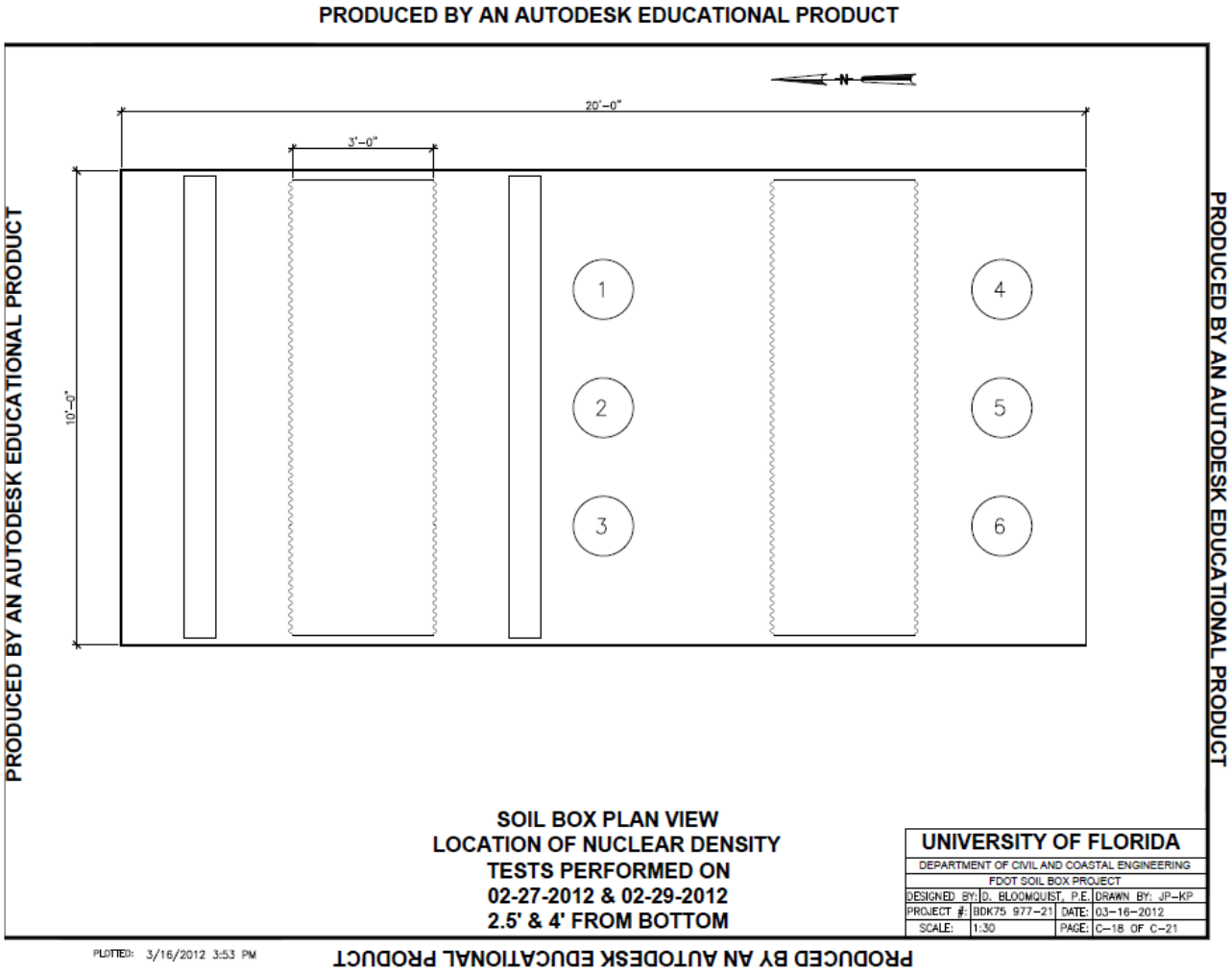

Figure 4-12. Plan view of locations of nuclear density tests 2.5 feet and four feet from bottom of Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 10 (Page 28). University of Florida, Gainesville, Florida.]

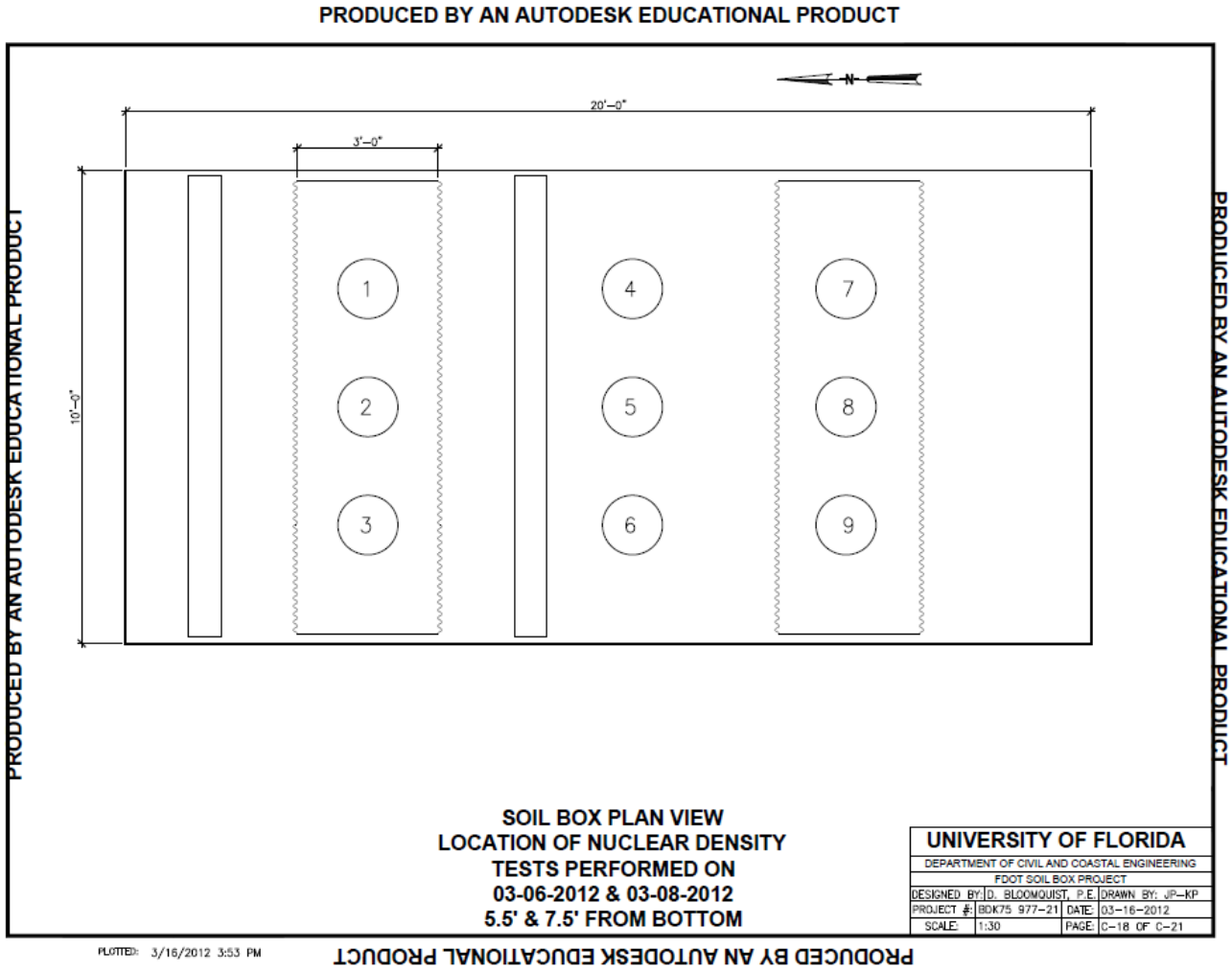

Figure 4-13. Plan view of locations of nuclear density tests 5.5 feet and 7.5 feet from bottom of Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 10 (Page 29). University of Florida, Gainesville, Florida.]

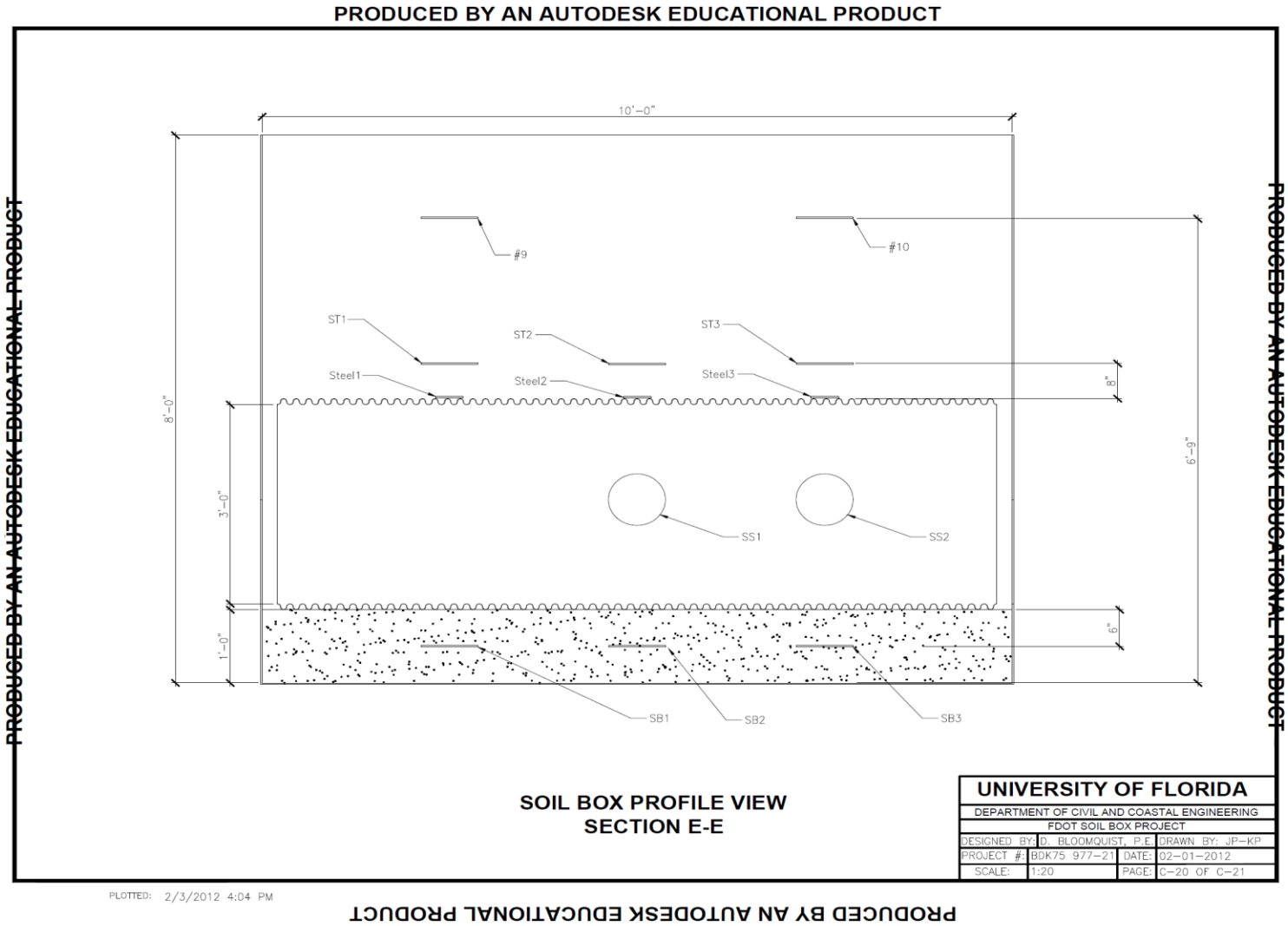

Figure 4-14. Profile view of the locations of earth pressure cells around the steel pipe. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 10 (Page 32). University of Florida, Gainesville, Florida.]

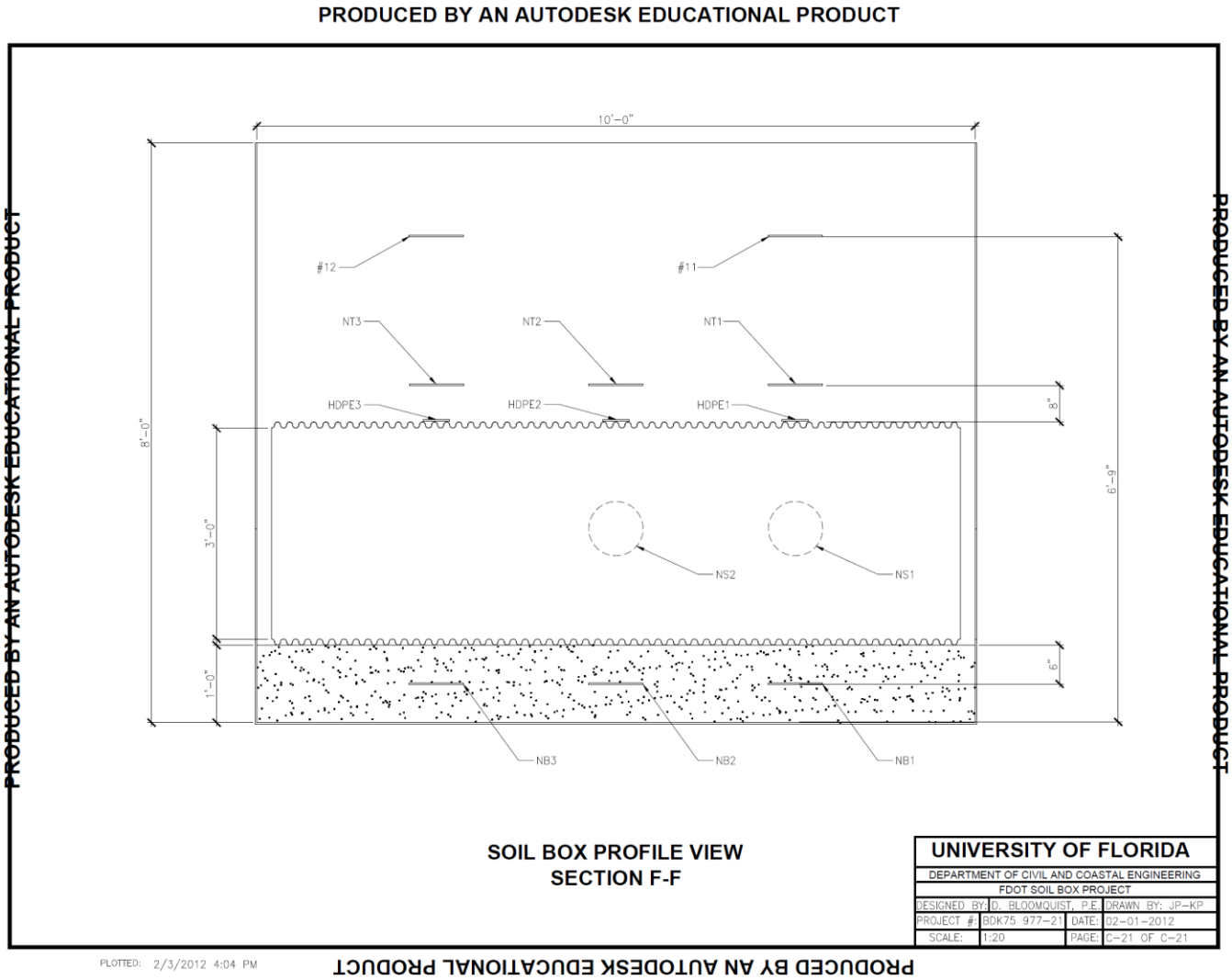

Figure 4-15. Profile view of the locations of earth pressure cells around the HDPE pipe. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 10 (Page 33). University of Florida, Gainesville, Florida.]

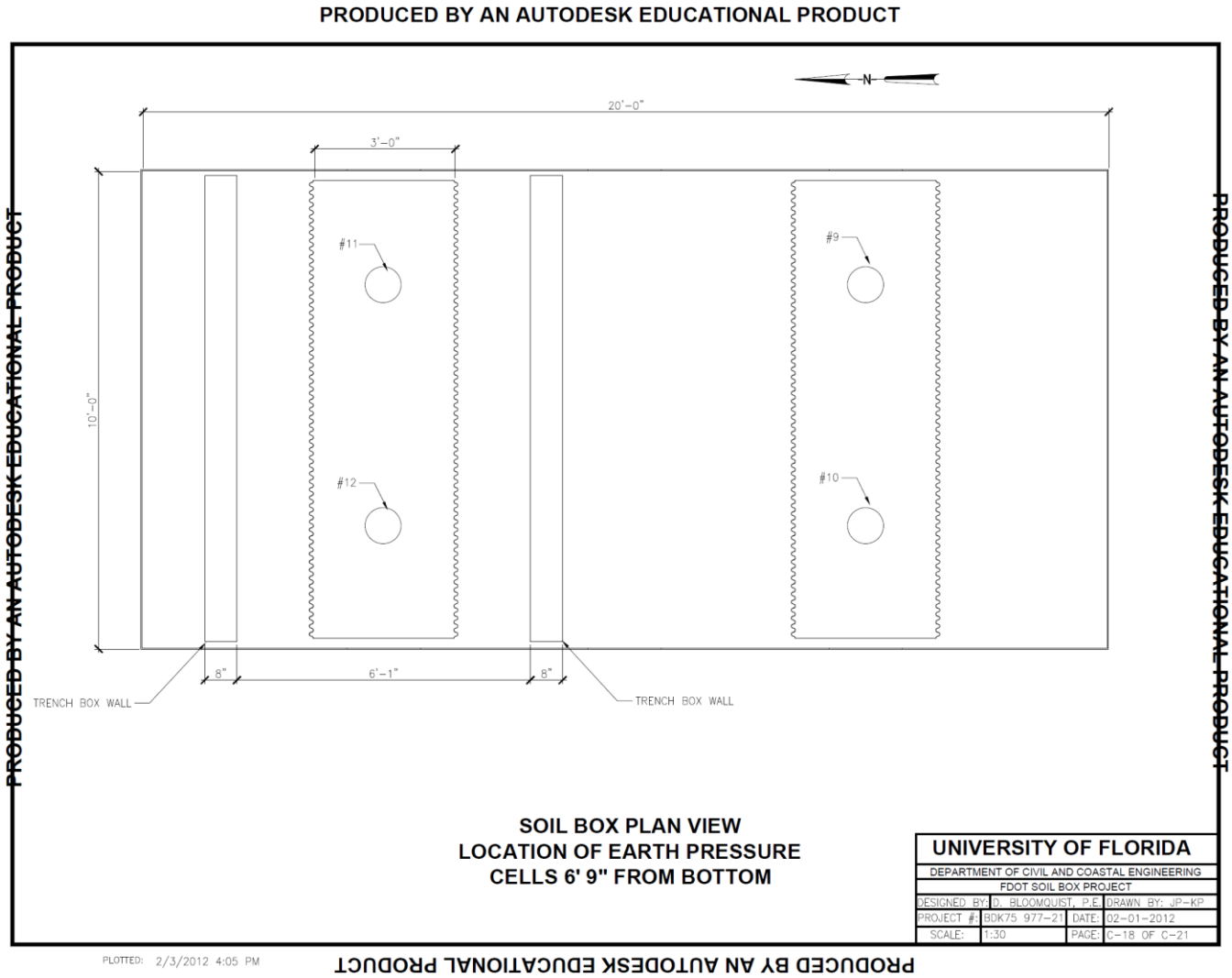

Figure 4-16. Plan view of locations of earth pressure cells six feet nine inches from bottom of Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 10 (Page 34). University of Florida, Gainesville, Florida.]

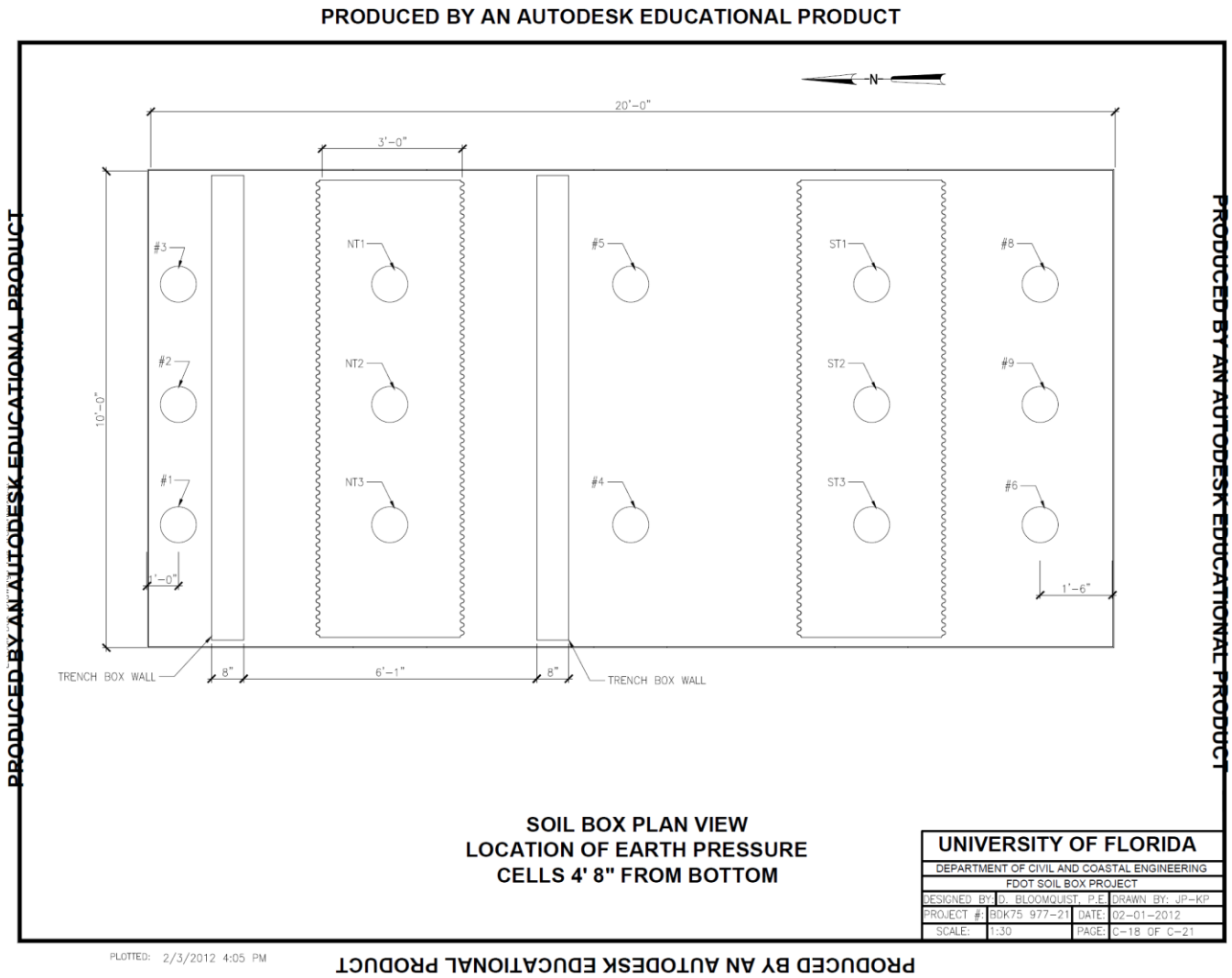

Figure 4-17. Plan view of locations of earth pressure cells four feet eight inches from bottom of Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 10 (Page 35). University of Florida, Gainesville, Florida.]

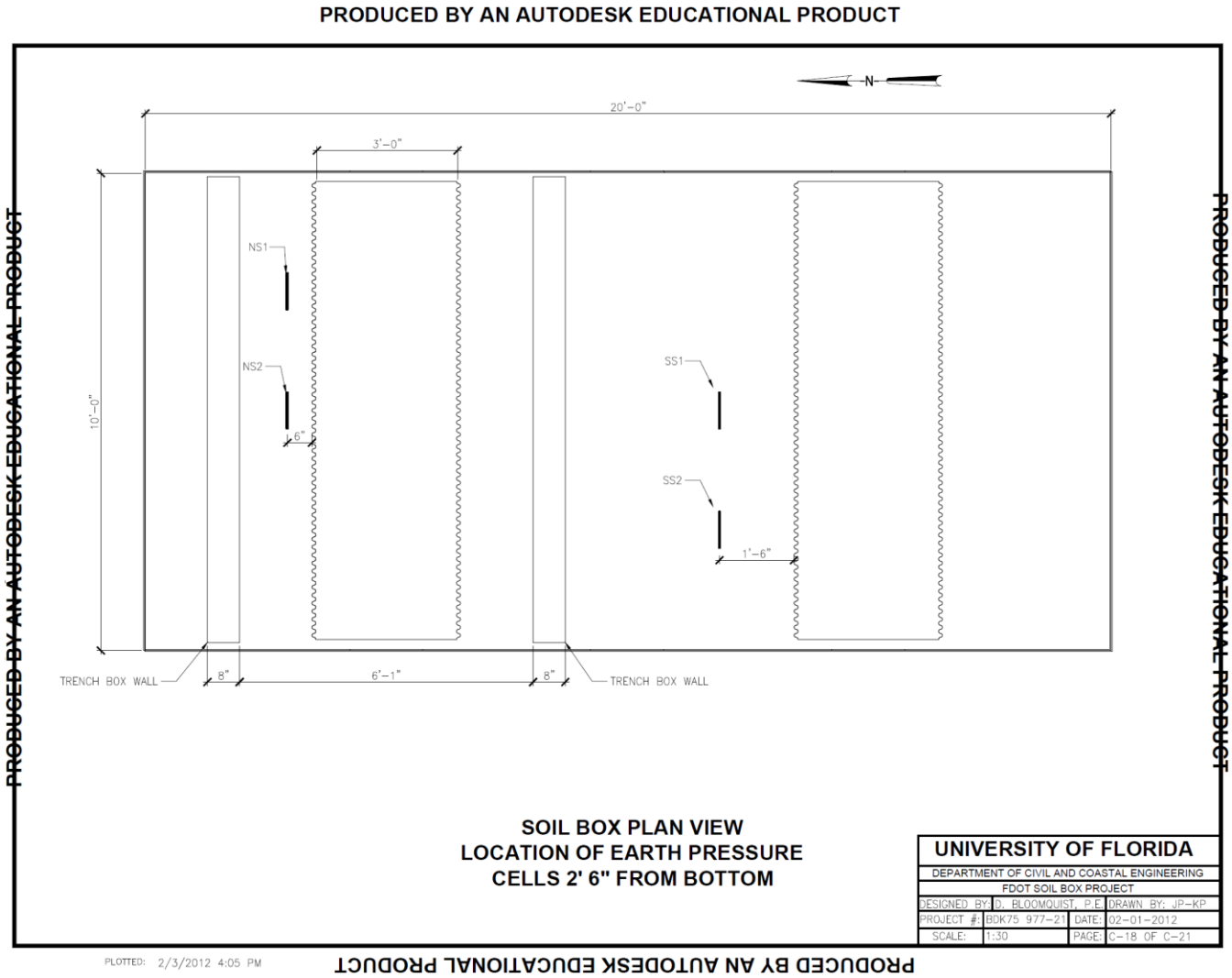

Figure 4-18. Plan view of locations of earth pressure cells two feet six inches from bottom of Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 10 (Page 36). University of Florida, Gainesville, Florida.]

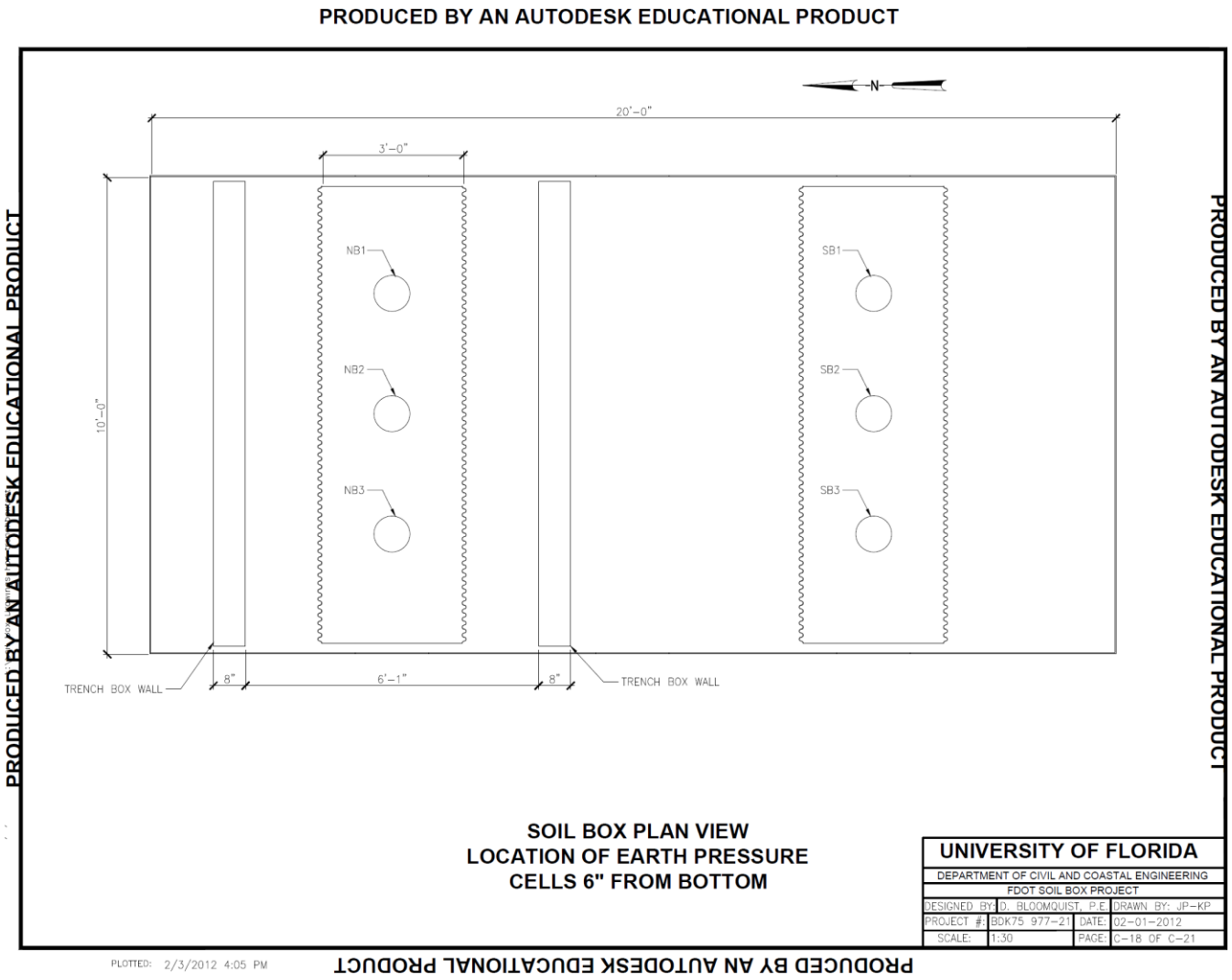

Figure 4-19. Plan view of locations of earth pressure cells six inches from bottom of Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 10 (Page 37). University of Florida, Gainesville, Florida.]

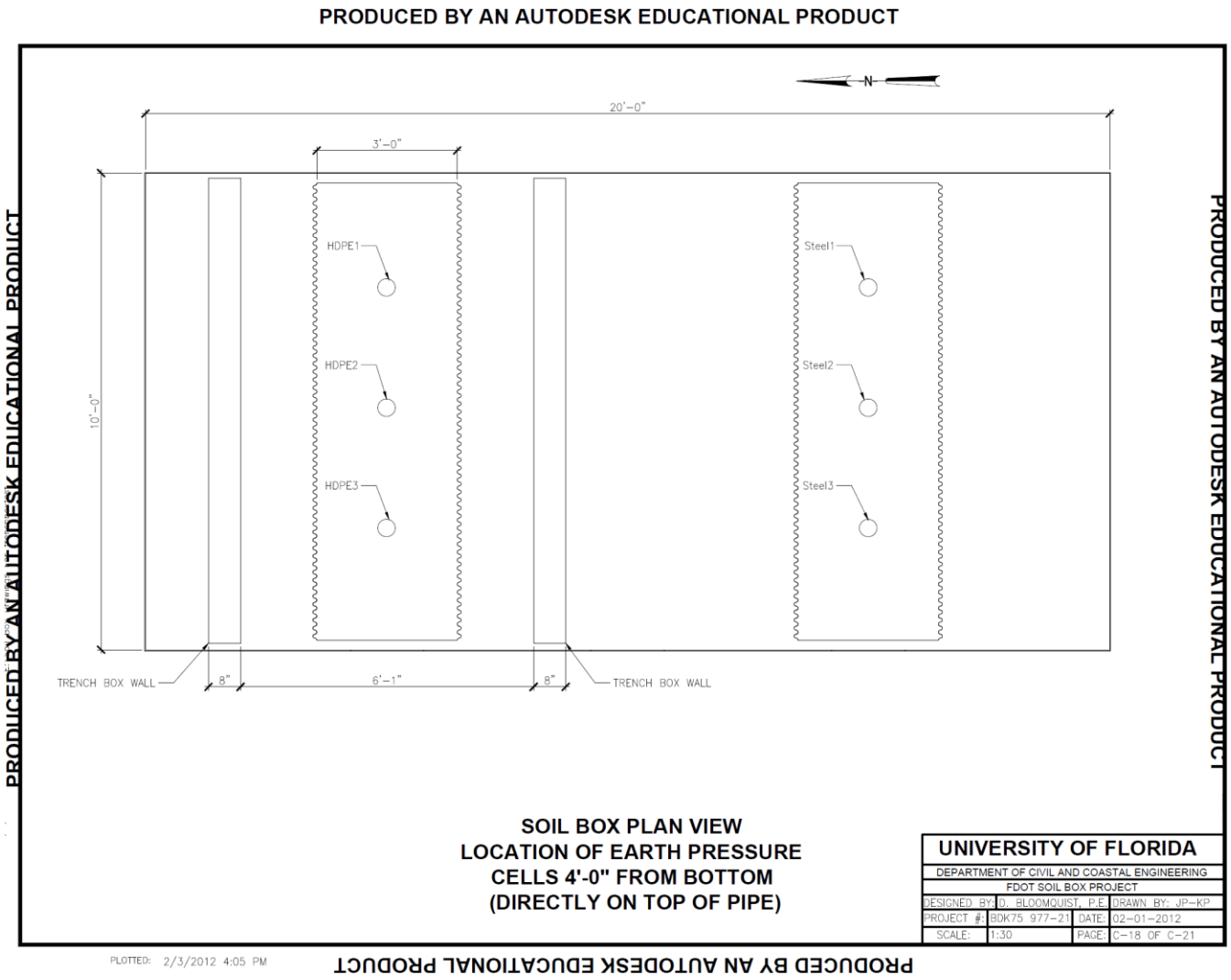

Figure 4-20. Plan view of locations of earth pressure cells four feet from bottom of Soil Box. [Reprinted with permission from Bloomquist, D.G.2011. BDK 977-21 Progress Report 10 (Page 38). University of Florida, Gainesville, Florida.]

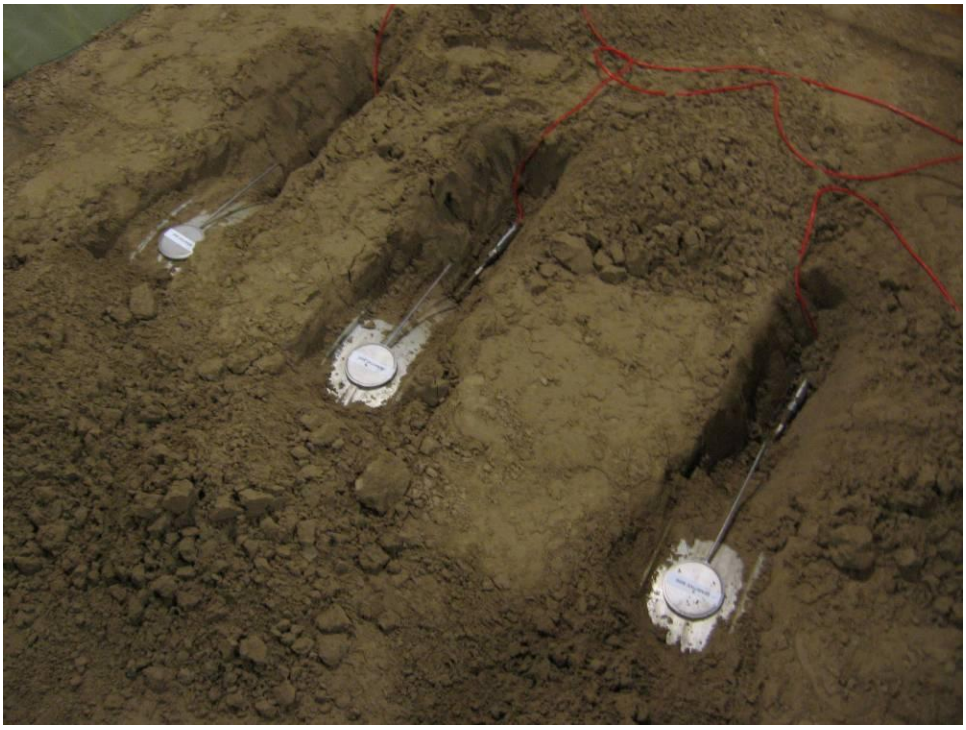

Figure 4-21. New small earth pressure cells installation. Photo credit: Z. Faraone.

Figure 4-22. Top view of void formed during saturation. Photo credit: Z. Faraone.

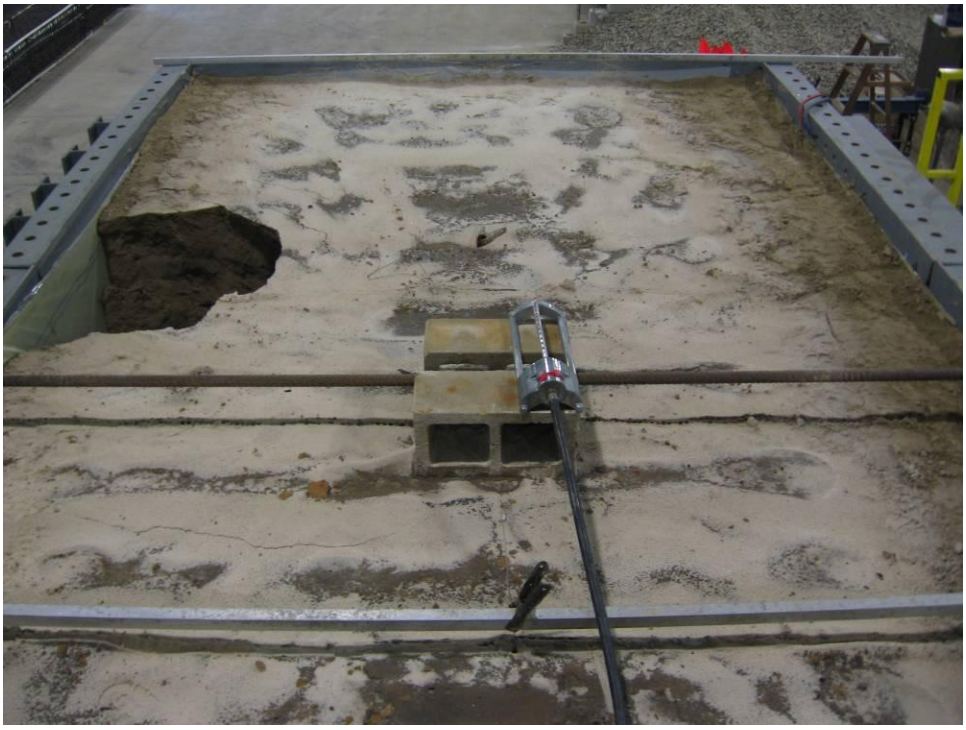

Figure 4-23. Top view of Soil Box showing void. Photo credit: Z. Faraone.

Figure 4-24. Soil piling up outside of porthole. Photo credit: Z. Faraone.

Figure 4-25. Soil piling up outside of Soil Box from porthole exit. Photo credit: Z. Faraone.

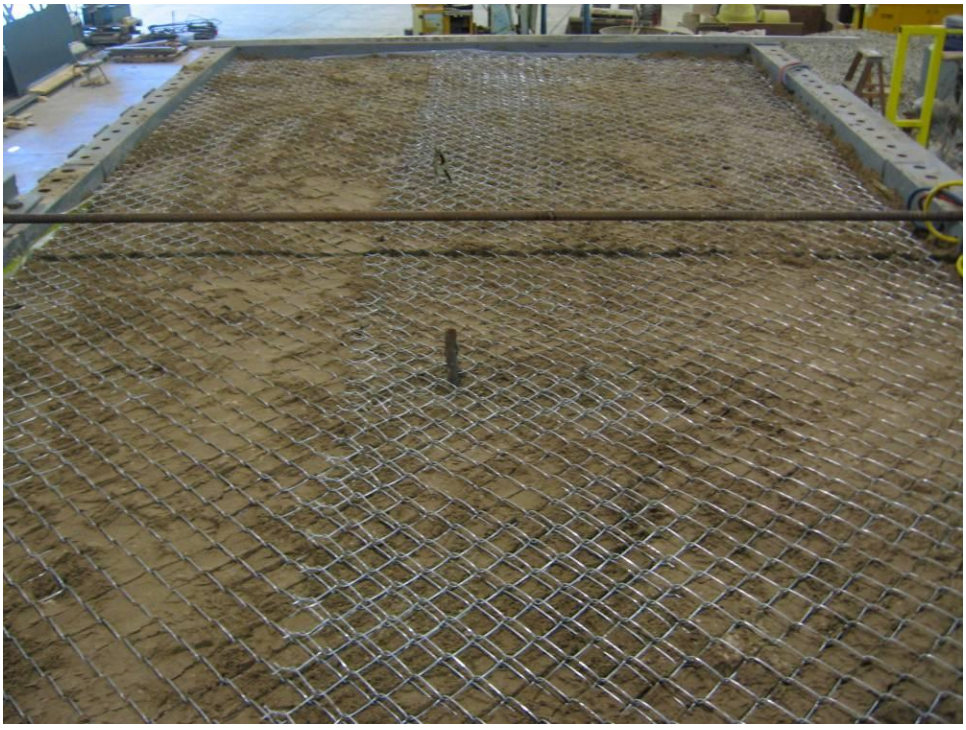

Figure 4-26. Chain link fence placed on top of soil in Soil Box. Photo credit: Z. Faraone.

Figure 4-27. Bubbles forming inside of the HDPE pipe during the loading sequence. Photo credit: Z. Faraone.

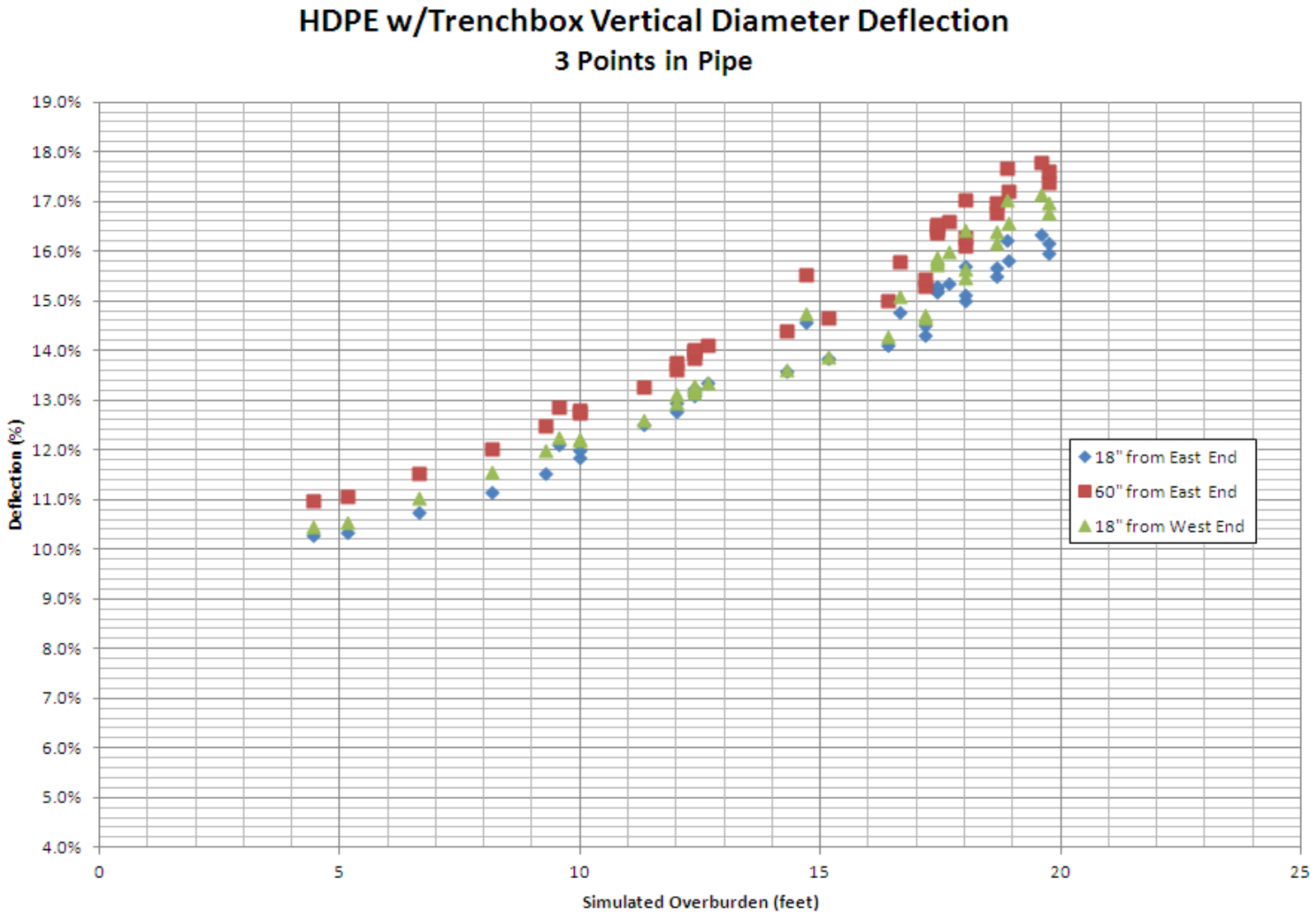

Figure 4-28. Deflection of thee points in the HDPE pipe during loading sequence.

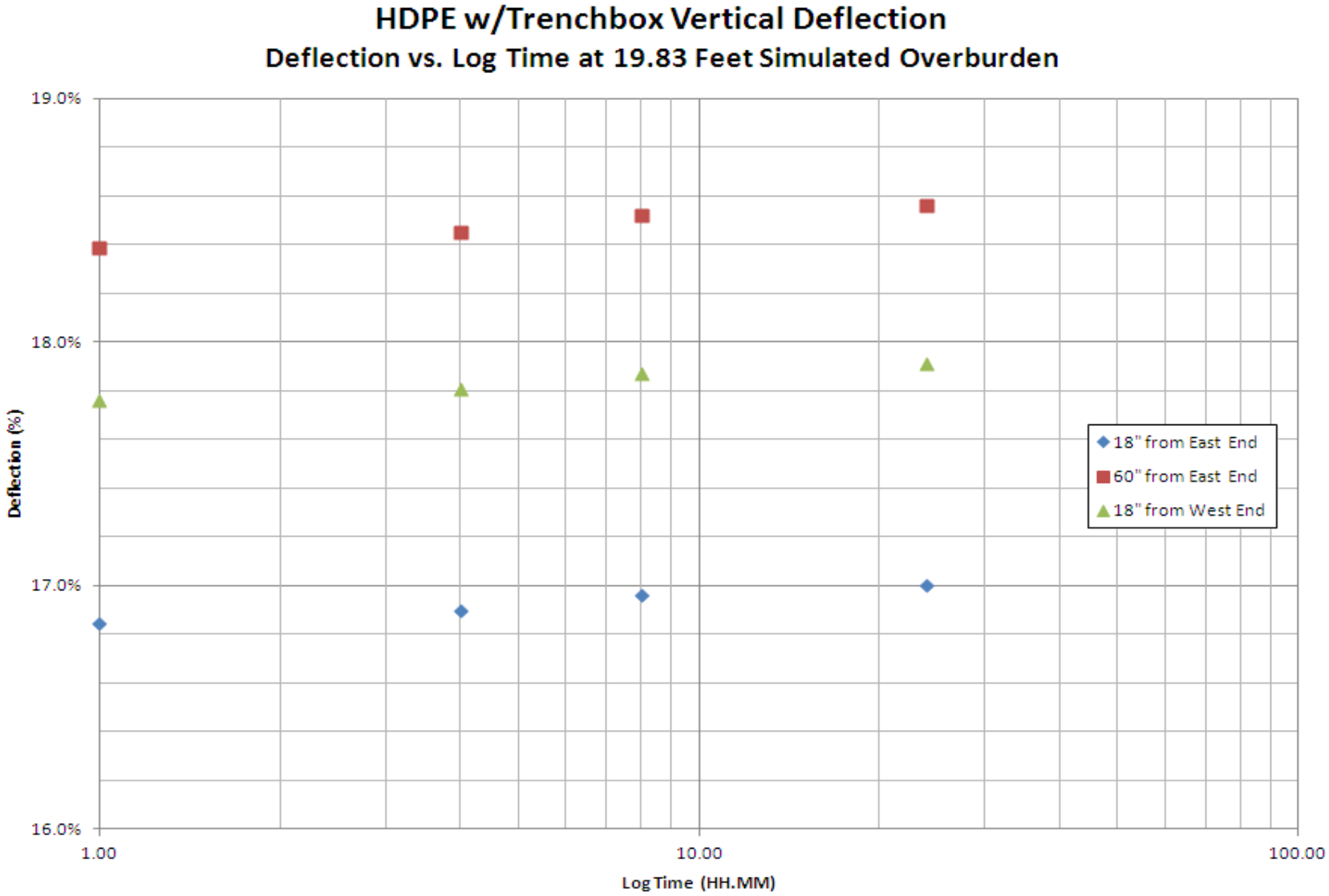

Figure 4-29. Deflection of HDPE pipe over a 24 hour period at 19.83 feet of overburden.

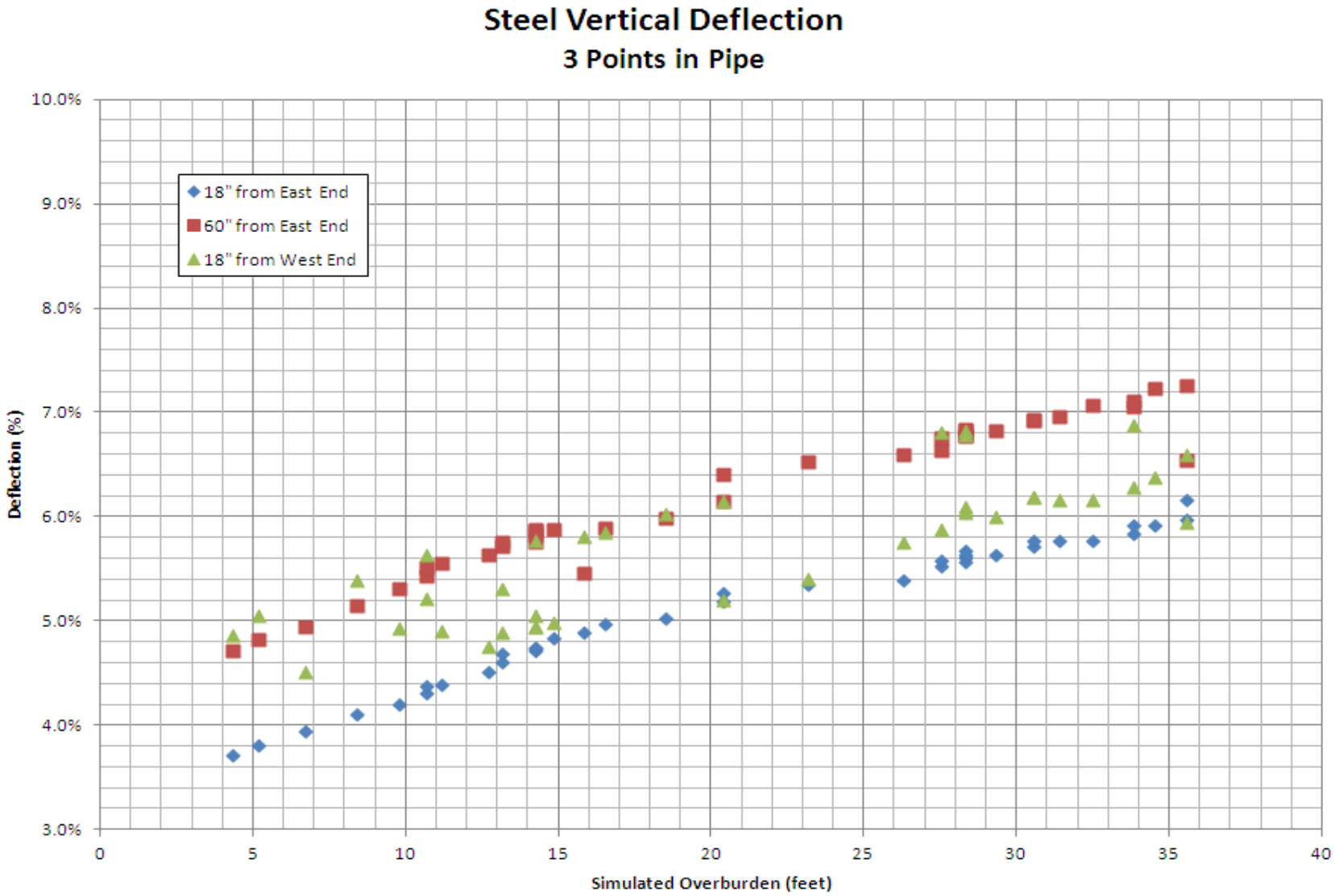

Figure 4-30. Deflection of three points in steel pipe.

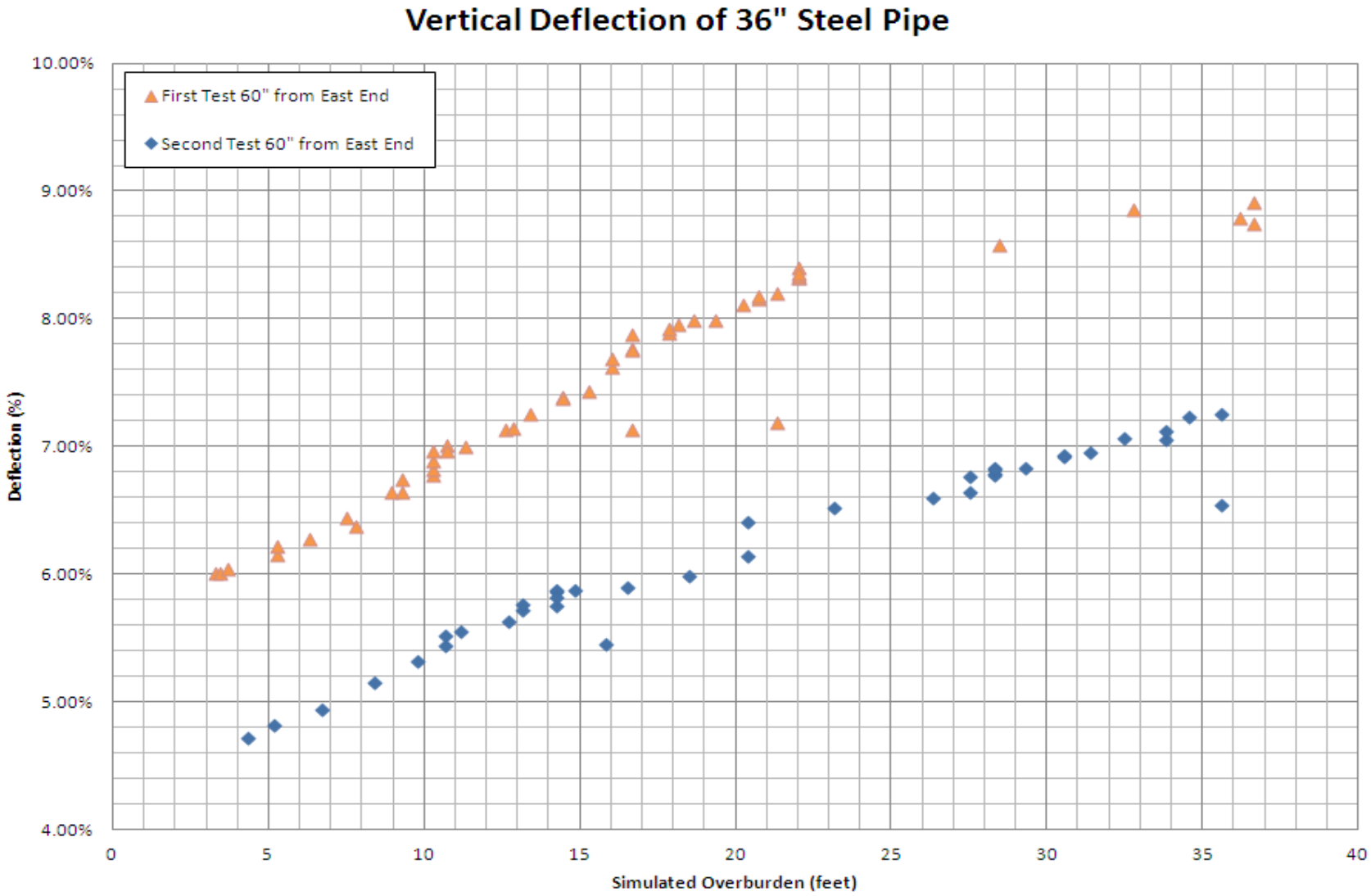

Figure 4-31. A plot of the deflections of steel pipes from different tests.

CHAPTER 5
CONCLUSION

At the conclusion of the fifth test during the Soil Box project the deflection data from each loading cycle compared very well. As expected the steel pipes being the most rigid deflected the least amount. The PVC pipes being the second most rigid had a greater deflection than steel. The most backfill sensitive pipe, HDPE, had greater deflections than all the pipes and when subjected to a trench box installation showed the maximum movements. A comparison of all these tests can be seen in Figure 5-1.

Overall, the results obtained so far during this research have proven to show a good trend towards flexible pipe characteristics. This project will continue on to test 24 inch HDPE and steel pipes to compare the deflections of different size pipes. Pending these results and comparisons with finite element analysis modeling conclusions can be made to better aid the FDOT in on site flexible pipe inspection.

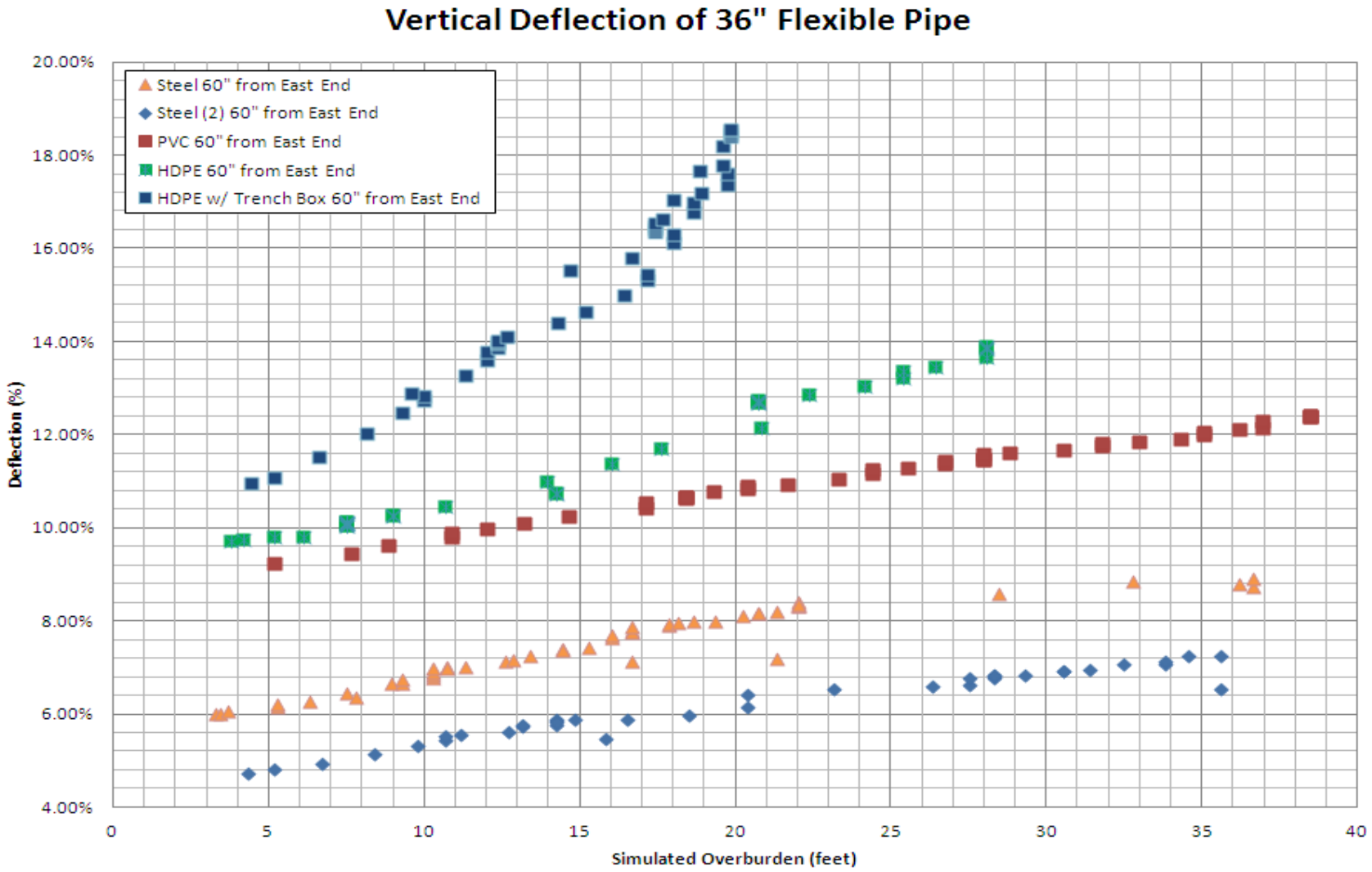

Figure 5-1. Vertical deflection of 36 inch flexible pipes.

APPENDIX A
LITERATURE REVIEW

The following articles have been collected throughout the project and are under review for their applications to the current research.

Abolmaali, A. (2008). "Experimental Verification of CUES Laser Profiler Deformation Analysis Results." University of Texas, Arlington, TX.

Brachman, R. W. I., Moore, I. D., and Rowe, R. K. (1996). "Interpretation of Buried Pipe Test: Small-Diameter Pipe in Ohio University Facility." *Transportation Research Record,* No. 1541, pp. 64-75.

Brachman, R. W. I., Moore, I. D., and Rowe, R. K. (2001). "The Performance of a Laboratory Facility for Evaluating the Structural Response of Small Diameter Buried Pipes." *Canadian Geotech. Journal*, 38, pp. 260-75.

CleanFlow Systems (2010). "Analyzing the Accuracy of Profiler Equipment and Software."

CleanFlow Systems (2010). "Profiler Reporting For Flexible Pipes."

Motahari, A., and Forteza, J. G. (2008). "Accuracy of Laser Profiling of Flexible Pipes Using CUES System." University of Texas, Arlington, TX.

Palmer, M. (2005). "Results of Full-Scale Test on 16-inch HDPE Pipe."

Sargand, S. M., and Masada, T. (2002). "Soil Arching Over Deeply Buried Thermoplastic Pipe." Ohio University, Athens, OH.

Smith, M. E., Beck, A., Thiel, R., and Metzler, P. (2005). "Designing for Vertical Pipe Deflection Under High Loads."

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Bloomquist, D. G. (2012). “BDK75 977-21 Progress Report 10.” University of Florida, Gainesville, FL.

Brachman, R. W. I., Moore, I. D., and Rowe, R. K. (2000). "The Design of a Laboratory Facility for Evaluating the Structural Response of Small-Diameter Buried Pipes." *Canadian Geotech. Journal*, 37, pp. 281-95.

Moser, A. P. (2001). “Buried Pipe Design.” Second Edition. McGraw-Hill. New York, NY.

The Plastics Pipe Institute Inc. (2011) “Corrugated Polyethylene Pipe Design Manual & Installation Guide.”

BIOGRAPHICAL SKETCH

Zachary Daniel Borah Faraone was born on July 16, 1987 to Stephen Faraone and Kathleen Faraone. He grew up on Sanibel Island, Florida going to school from pre-school to 8th grade.

Following middle school he enrolled into the International Baccalaureate (IB) program at Fort Myers High School. While attending high school he worked at a local grocery store. During his time in the IB program and working at the grocery store he learned how to have a strong work ethic while balancing his time between school, work, sports, friends, and most importantly family.

Attending the IB program allowed him to receive a scholarship for full tuition to any in state college. He decided to follow in his older brothers footsteps and attend the University of Florida. There he started as a civil engineering major. While attending college he obtained a part-time research position under Dr. Bloomquist and Dr. McVay. This position opened his eyes to the specialty of geotechnical engineering. After completing his Bachelors of Science in Civil Engineering he decided to pursue his Masters of Civil Engineering at the University of Florida. While attending classes he continued his research assistantship which allowed him to receive a full scholarship for his masters.

Upon completing his requirements for his masters degree he will begin working for Ardaman & Associates in Tampa, Florida as an entry level staff engineer continuing to add to his knowledge of geotechnical engineering.